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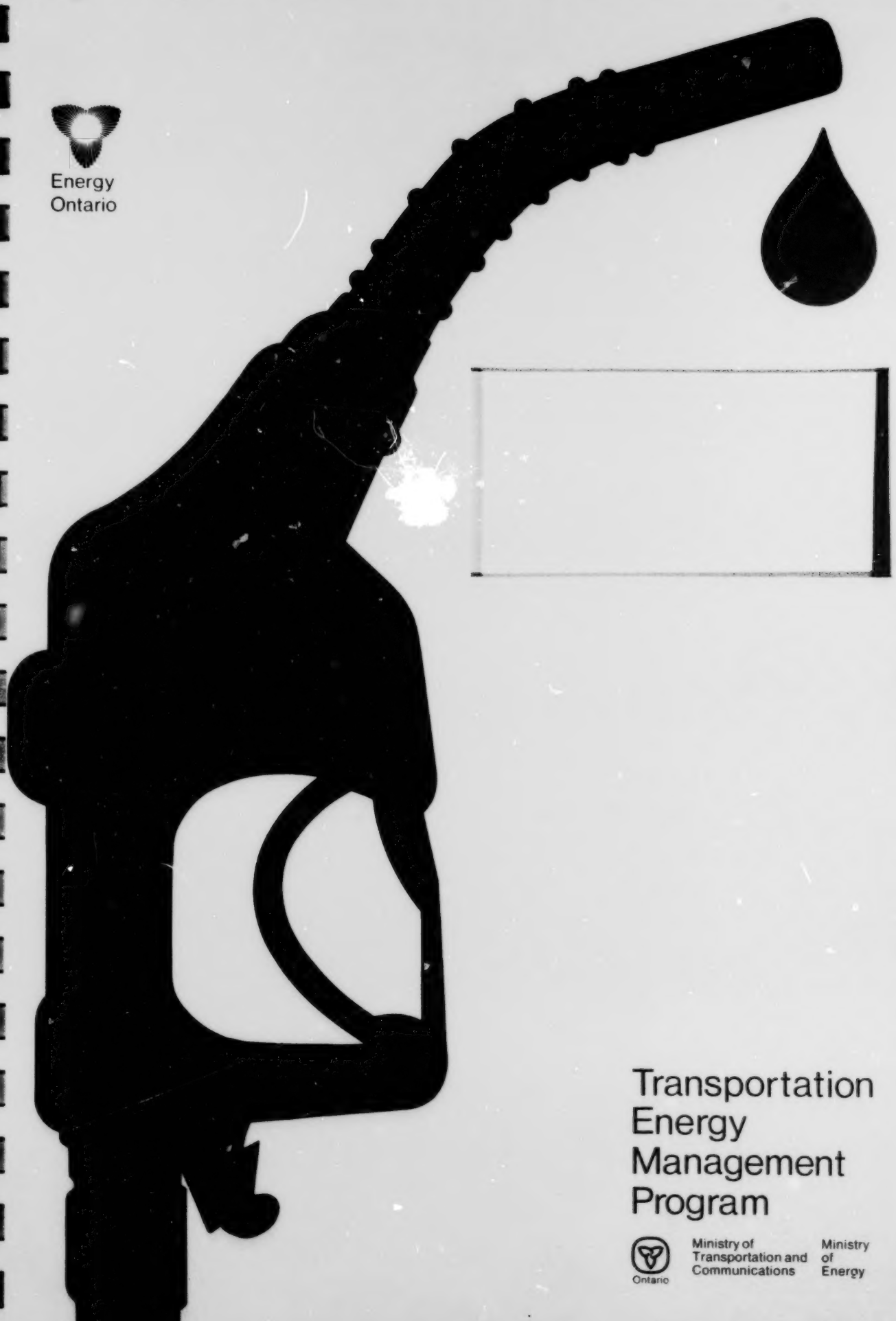

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Driver Aid Devices for Fuel Economy

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Driver Aid Devices for Fuel Economy

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SUMMARY

It has been well established that vehicle fuel economy is significantly affected by the driver and the way he exercises his control. However, present devices designed to aid the driver to improve fuel economy appear to be only marginally effective.

The present study represents an in-depth review and critical assessment of the following.

1/ Fuel-economical driving practices and their relationship to the underlying vehicle parameters that can be used to provide driver aid.

2/ The devices that monitor those parameters -- a listing of available devices that are potentially effective, and a critical assessment of their purpose, use instructions, previous evaluation studies and cost-effectiveness.

3/ Test procedures and results.

4/ Driver aid devices introduced by new vehicle manufacturers.

In addition, the study includes a brief discussion of new vehicle improvements affecting the use of driver aid devices.

In regard to fuel-efficient driving practices, the study deals with one important point not clearly established. That is, that the optimum variation of acceleration level with respect to vehicle speed differs for manual and automatic drives. This has a potentially significant effect on fuel economy.

Of the vehicle parameters that can be used to aid the driver, throttle, manifold vacuum, vehicle speed, engine speed and fuel economy are all considered useful. In addition, specific fuel consumption (SFC) is

suggested as the optimal control parameter for transient operation because it is an indicator of engine and driveline efficiency. In consequence, a device concept to monitor SFC is suggested.

The existing cost-effective devices that monitor vehicle parameters include the vacuum gauge, the vacuum buzzer, and the upshift indicator. The MPG meter (the trade name for the L/100 km indicator in Canada) is not cost-effective at the current Canadian prices.

A review of the various devices and the instructions for their use revealed that for many, the relationship between the feedback or control function and vehicle operation has not been properly established.

Cost-effectiveness figures based on a three-year payback period were derived for 12 devices which have been found effective to some degree. Some devices could be more appropriately used with either a manual drive (M) or an automatic drive (A). Among the existing devices, the highly cost-effective ones include the vacuum gauge, vehicle speed device (speedometer overlaid with special markings) (M) and vacuum buzzer; the marginally cost-effective ones include accelerometer, upshift indicator (M) and RPM meter (tachometer overlaid with special markings) (M); the cost-ineffective ones include MPG meter and cruise control.

The cost-effectiveness figures are estimates and must be considered preliminary. In particular, the cost of the MPG meter, which is still under development, may come down, especially if produced in Ontario.

A review of three major, relatively recent test studies concluded:

- The vacuum gauge and the MPG meter both give a 3-5% fuel economy gain by the average driver when used over a sufficiently long period of time to include a significant fall-off in effectiveness; a similar gain is achieved by training in fuel-economical driving practices alone.

- A vacuum buzzer alone gives a 2 to 3% improvement.

- Fuel cost saving does not seem to provide an incentive of any consequence for driving fuel-efficiently.

- The form of the feedback is very important. For example, a dial-type vacuum gauge is effective whereas the piston type is not. Also, buzzer and voice delivery tend to be irritating and are likely to be disconnected.

- Digital feedback is acceptable and appears effective with certain devices.

- Selected devices can be combined to good effect (e.g., vacuum buzzer and MPG meter).

As a general observation, large-scale road and field tests should be undertaken only once a device is well understood and its fuel economy potential under controlled conditions has been well established. If possible, the driving conditions should be monitored to some degree to allow the extraneous influences to be factored out and to reduce the scatter of data.

From an evaluation of the specific makes of the devices available on the market, the vacuum gauge was assessed to be adequately accurate and reliable, but with most makes the dial displays were wanting and the packaging less than ideal. Only one vacuum buzzer make is available but it is generally satisfactory. Two good quality MPG meters, each offering a number of functions, are on the market. The problem is that the most effective functions and their form have not yet been established and, while the prices have dropped considerably, at the current Canadian retail price of $150, an MPG meter is still not cost-effective. No Canadian-made devices of any kind are offered.

Significant improvements in driveline design and fuel-economical engine/transmission control which have been under development by vehicle manufacturers are starting to come on line. These may have sigificant impact.

These developments fall into four categories:

- automatic transmission improvements,
- higher overdrives with manual transmissions,
- fuel-economical engine control in deceleration and idle, and
- introduction of selected driver aid devices.

In general, the importance of the add-on devices is not expected to diminish; however, there will be shifts in emphasis.

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PREFACE

This project has been undertaken by PILI Consultants Inc. under contract with the Ontario Ministry of Transportation and Communications (MTC). It is a response to the need, as established by MTC, to research the background and potential usefulness of devices that help motorists to improve fuel economy through modifying their driving habits. Also, in order to establish what MTC should be doing to promote fuel conservation from this measure, the optional courses of action were to be laid out. According to the project statement, the study is to address the following:

- Technical state-of-the-art concerning driver aid devices.
- Existing and in-progress studies to establish the potential of the devices.
- Market expectations and introduction of devices on new vehicles.
- Directions for MTC to pursue and specific recommendations for MTC to consider with respect to the devices.

The data used in this study, as compiled from various references, are commonly in British units, as are the functional designations of devices such as the MPG meter. As much as possible, these data and designations will be presented here in metric units. However, this is not feasible in every respect without rendering reading and comprehension difficult. It is hoped that for future work all data can be presented in the metric form.

1/ INTRODUCTION

1.1/ Background

The driver of a road vehicle is an integral part of its control system. Aside from directional control through the steering wheel, he senses traffic and the operational states of the engine, transmission, and the vehicle and provides the primary control of vehicle speed and acceleration through the accelerator, brake, and gear shift. In the following, "vehicle control" and "vehicle driving practices" or techniques refer to the control of the vehicle propulsion/braking system and not steering.

Secondary control is provided by automated means which commonly includes mixture ratio, spark timing, exhaust gas recirculation and choke -- all of which affect fuel economy. In addition, the shift points of an automatic transmission are controlled automatically by sensing engine RPM and manifold vacuum.

Fuel economy depends significantly on how the driver exercises his control. Thus, an attempt to improve that control must start with the establishment of a set of fuel-economical driving practices. At that point, the driver can be either trained to drive according to these practices or specific driver aids can be provided to assist him in doing so. That ties driver training and driver aids together such that they can replace or complement each other. The report covers the specific devices used as driver aids, referring to the training aspect where appropriate.

While driver training has been fairly effective in improving fuel economy, it tends to be troublesome and costly -- and the fast relapse to the accustomed driving practices is a big problem. Also, certain driving practices involve fairly careful control which can present difficulties to the average driver. Although more costly than driver training, well-conceived driver aid devices providing prompting, feedback or even some degree of control overcome these drawbacks to a larger or lesser degree and should prove more cost-effective in the end. In particular, a well-conceived informative device is expected to maintain driver interest for as long as it remains installed in a vehicle. However, it is important

that that the devices be supplied together with carefully developed instructions. In a different approach, the devices could be used to facilitate driver training.

A number of studies have been made of fuel-economical driving practices and driver aid devices, but only a few are "in-depth". Also, only a few studies involve rigorous simulation and well-controlled testing. As a consequence, some of the advice on fuel-economical driving is contradictory. Nevertheless, what has been done indicates a fair potential for fuel economy improvement. The potential is there for an average fuel economy improvement in the order of 20% through the use of driver training, driver aid devices or a combination thereof. L. Forrest [8], from an analysis of a number of test results, establishes a conservative "assigned fuel economy improvement potential" through driver training at 10%.

The fuel saving would apply to both automobiles and light-duty commercial vehicles, which together consume approximately 75% of the transportation fuel in Canada (80% of the total automative fuel consumption). This gives an indication of the fuel saving potential from a broad adoption of driver aid devices.

A large number of driver aid devices have been introduced to the market to tap this potential. However, many appear ill-conceived, display obviously exaggerated claims, and come with questionable use directions. Since there is no readily available information on their actual in-use effectiveness, the average buyer would be hard put to know which ones are worth their cost.

Also, vehicles have differing control characteristics depending on whether they are equipped with manual or automatic transmissions -- even the type of automatic transmission affects fuel economy. Therefore, different fuel-economical driving practices may apply in each case depending on vehicle characteristics, and either the devices themselves need to be interpreted differently or their output needs to differ. Accordingly, instructions for use may have to be more sophisticated than they are now.

1.2/ Definition and General Classification

For the purpose of this study, a "driver aid device" is defined as any device that provides feedback or prompting to the driver or assists in the control of the vehicle to promote the use of fuel-economical driving practices. This includes two levels of monitoring:

- direct monitors, which work more or less in real time providing immediate feedback and control; and

- indirect monitors, which accumulate information and provide a record for the driver at the end of a trip or a segment of a trip.

The direct monitors can be used readily by the average driver and would have by far the larger fuel saving impact. The bulk of this report is devoted to these. The indirect monitors are covered in Section 4.3.

2/ WORK STATEMENT

2.1/ Development of Objective

A preliminary review of previous evaluation studies and the information supplied with the devices reveal a lack of an engineering basis for the devices as components of automotive technology. It appears there has never been any systematic R&D in this area. For instance:

- The relationship between the feedback or control function of a device and vehicle operation is obscure. It is difficult to relate a device to fuel-economical driving practices, to compare devices for their effectiveness and to establish how they complement each other and how their functions might overlap.

- Several misconceptions and contradictions were discovered which are not addressed even in the more recent investigations.

- There is no way to assess the impact of changing vehicle technology.

- The various driving test results are strongly inconclusive showing large variations in the effectiveness of the devices (e.g., the fuel economy gain from a vacuum gauge ranged from -17% to +25%).

Thus, instead of starting with a straightforward listing and evaluation of devices based on the available data, the decision was made to start with fundamentals and to develop the groundwork for systematic R&D and evaluation first. After that, the various device concepts would be assessed on solid technological grounds to establish what is effective and what is not.

From this would emerge performance requirements and design criteria for the devices and opportunities for improvement and filling gaps (perhaps suggesting new devices). Also, any errors and inconsistencies would be uncovered. With the inter-relationships between feedback and vehicle functioning clearly established, there is a basis for estimating the potential effectiveness of the devices. Along with a critical review of

device tests, this approach would lead to a reasonably well-founded set of recommendations and a well-directed implementation program for MTC.

Without such a critical "systems" approach, any driver aid device demonstration and implementation program would likely meet the fate of previous tests and demonstrations -- showing only a marginal fuel economy improvement potential from the devices and, in general, being inconclusive.

This outlines the broadened objectives of the study.

2.2/ Approach

2.2.1/ Driving Practices

- Establish the fuel-economical driving practices and the appropriate driver control actions.

- Explain each driving practice based on the propulsion system and vehicle operational characteristics. Consideration should be given to the differences in manual and automatic transmissions.

- Establish the fuel saving potential of each driving practice.

2.2.2/ Parameters/Concepts

- Develop a list of all control parameters and concepts which could be used to prompt the driver to drive fuel-economically or assist him in doing so (list known ones and suggest new ones).

- Describe in technical terms how each parameter or concept relates to fuel consumption and fuel-economical control.

- Establish the effectiveness of each parameter or concept in providing meaningful feedback to the driver or actually performing a control function with respect to all the specific driving practices.

2.2.3/ Devices (Generic)

- Relate each monitoring function to a specific device type. If no appropriate device is known, suggest a device configuration to suit the need.

- Estimate the cost of each device and calculate its cost-effectiveness.

- Extract a list of effective and cost-effective devices and combinations of such devices.

2.2.4/ Evaluation

- On the basis of features and cost, select representative devices on the market for evaluation.

2.3/ Terms of Reference

1/ The investigation covers vehicles with four-stroke cycle spark ignition engines only. This includes carbureted and fuel-injected engines and specifically excludes diesel engines for which many of the devices covered here do not apply.

2/ The impact of cold weather on device effectiveness should be commented on. If cold weather presents a complication, it should be pointed out for future study.

3/ While there may be significant differences in the effectiveness and proper use of a device on vehicles with small vs. large engines or low vs. high power-to-weight ratios, these differences will not be explored in detail here.

3/ FUEL-ECONOMICAL DRIVING

3.1/ Fuel-Economical Driving Practices

To achieve the maximum fuel economy gain through skillful driving, specific vehicle driving practices must be followed. (As noted in the introduction, "driving practices" refers here to the control of vehicle speed and acceleration.) These practices differ somewhat depending on whether the vehicle has a manual or automatic transmission and whether the automatic transmission is conventional or features a lock-up (split torque) torque converter, or some other economy mode control.

The practices apply to everyday driving and need not seriously conflict with the tendency by many drivers to drive aggressively. For example, over a typical suburban trip in a car equipped with an automatic transmission, if brisk acceleration is limited to lower gears only instead of accelerating briskly all the way to the cruising speed, a fuel economy gain of around 10% would be realized [7]. The corresponding increase in trip time would be around 3%.

Compiled in Table 1 are nine basic fuel-economical driving practices. Where appropriate, specific driver actions relating to the control of throttle, gear shift and brake are indicated. This listing is the first step in establishing the most appropriate devices for fuel-economical driving.

The list is complete in that it covers the basic driving situations where fuel saving is possible. However, it does not include every possible bad driving habit -- for example, accelerating to a higher speed than necessary if one must immediately slow down again. This could probably be classified under "erratic driving" which is listed.

With each driving practice is listed the estimated potential fuel saving in percent. The figures represent the potential saving by a relatively alert, motivated driver over the EPA composite driving cycle (55% city, 45% highway driving), starting from the fleet average fuel economy levels and assuming first-rate devices and use instructions.

It is well to point out that driver training is an alternative to the use of a device. However, it is the writer's opinion that such training alone without the benefit of prompting by a device in executing a driving practice will be less effective. Still, driver training may be a useful adjunct to the instructions for the use of a device and the use of good fuel records to monitor driver performance may help to improve the effectiveness of driver training.

The figures in Table 1 are derived for the prevailing Ontario conditions of 100 km/h freeway speed limit and relatively flat terrain and the trade-off between fuel economy and driving time has been taken into account. Such figures, however, were not available directly and had to be derived from various test and simulation results or estimated using engineering judgement.

3.2/ Potential Fuel Saving

The derivation or source of each of the potential saving figures in Table 1 is presented below.

1A/ Acceleration -- MANUAL (6%). From data by Volkswagen, an increase in City Fuel Economy of 8% is achieved from the use of the upshift indicator. Adjusting this figure downward for the EPA Composite Cycle and allowing for an incremental increase in the acceleration level possible with private drivers, boosting the gain, yields an approximate potential of 6%.

1B/ Acceleration -- AUTOMATIC (6%). From computer simulation [7], the difference between the best and worst case acceleration fuel economy is approximately 12% for a suburban trip. From a consideration of the typical U.S. acceleration profiles (compiled by Volkswagen) the average of possible improvements appears to be about half of that.

2/ Short Grades (1%). No pertinent fuel economy data were found. Observing the frequency of the opportunity and the tendency by the average driver to follow the recommended driving practice to some degree, a 1% saving potential was assigned mainly from relating it to vehicle acceleration.

3/ **Long Ascent (0%).** At the present time in Ontario this driving practice is expected to have a negligible impact owing to the relatively flat terrain. Also, the relatively high power available in the top gear of the average vehicle will allow ascent without slowing down. That situation may well change in the future.

4/ **Cruise Speed (2%).** Data in Reference 1 show a 10% fuel economy improvement from the cruising speed dropping from 100 to 90 km/h. Over a composite driving cycle appropriate for Ontario (a 100 km/h freeway speed limit), this might yield an average of 3 to 4% improvement. However, many drivers would not be willing to reduce cruising speed for a fuel economy gain.

5/ **Avoid Power (2%).** Tests by Bendix [2] show a fuel economy gain of 2 to 3% from the use of vacuum buzzer which gives a direct indication of the potential from this driving practice.

6/ **Avoid Pumping (1%).** At a pump capacity of about 2 mL if the pump activation can be avoided once every two minutes the saving would come to approximately 1%. (Pump activation appears more likely with manual drives requiring accelerator depression with every gear change.)

7/ **Avoid Erratic Driving (4%).** Comments made in several references imply that erratic driving incurs a significant loss in fuel economy, although no data were given to support this. It appears that erratic driving provides a somewhat less significant opportunity for fuel economy than acceleration.

8/ **Utilize Kinetic Energy (6%).** From computer simulation [19], the braking energy loss over the EPA Composite Cycle is 18%. Since that cycle does not include any coasting, contrary to the experience with the average driver, the actual braking energy loss is reduced to perhaps 12 to 15%. It is assumed that an alert, motivated driver can reduce that loss by half.

9/ **Minimize Idle (2%).** An idle engine switch-off scheme involving automatic starting by means of a small flywheel, currently under development by Volkswagen, is estimated to save 5% of fuel for the average driver. A conscientious driver with a driver aid might optimistically save 2%.

The total potential fuel saving from these driving practices is 24%. This appears a reasonable figure in light of the finding that the worst driver uses approximately 1.5 times as much fuel as the best driver ([18, 20] and communication with the U.S. DOT). As noted in Section 3.1, however, the 24% potential fuel saving is the estimated improvement obtainable by an alert, motivated driver aided by effective devices. The improvement is referred to the fleet average fuel economy level. As other investigators have done before, the fuel saving figure for planning purposes achievable by the average driver aided by effective devices is assumed in this study to be half of the above figure, i.e., 12%.

3.3/ Specific Fuel Consumption

Before presenting commentary on each driving practice (given in the next subsection), it is useful to introduce the concept of "specific fuel consumption" (SFC) which is the basis for several of these practices. It appears that feedback involving SFC could achieve a large extra increment of fuel economy over and above the full fuel economy potential from the fuel-economical driving practices alone.

3.3.1/ The Concept

SFC refers to the amount of fuel consumed (in litres, grams or gallons) for each unit of energy output (either kilowatt-hour (kWh) or horsepower-hour (hp-hr)). The lower the SFC, the less fuel is consumed for a given amount of work done and the better the fuel economy.

A spark ignition engine under favourable conditions converts about 30% of the fuel energy into useful mechanical work. In other words, it has a thermal efficiency of 30%, which corresponds to approximately 250 g/kWh. The favourable conditions include, in particular, an open throttle which

allows the engine to pull air in freely with minimal pumping loss. That produces a high torque (turning force) or engine loading at a low SFC or a high thermal efficiency. At partial throttle, the fuel-air charge density drops and at a given RPM the engine generates less torque. It also uses less fuel but at the same time extra work is required to pull air into the cylinders through the partially-closed throttle. The net result is that while the fuel flow rate drops, the power output drops even faster and the amount of fuel spent in doing 1 kWh of work actually increases. For example, decreasing throttle from a given setting to reduce torque by 50% may reduce fuel flow rate by only 30%. As a result, the SFC has actually increased by 40% (engine thermal efficiency has dropped). Thus, contrary to popular opinion, the four-stroke spark ignition engine is inherently most efficient operating at wide open throttle (maximum engine loading) at any given RPM. It is diametrically opposed to the diesel engine in this respect.

An SFC map for a 1.8 L engine is shown in Figure 1 [14]. The SFC contours are plotted on a grid of brake mean effective pressure (BMEP) representing engine loading vs. RPM. On the map, the relatively high efficiency region extends roughly from 1200 to 3600 RPM and from 60 to 90% of maximum engine loading. The increase in SFC at the highest levels of engine loading is caused by power enrichment.

3.3.2/ Importance

SFC comes into play in all transient driving situations (acceleration, speed changes, driving over uneven terrain) presenting a choice of engine loading schedule through the manipulation of throttle and gearshift or throttle only with an automatic drive. It appears that minimizing SFC is the basis for over 50% of the potential fuel economy gain from fuel-economical driving. Feedback and control based on other principles can, to a degree, take the place of SFC, but minimization of SFC should be the aim in transient driving situations (see next subsection). An instantaneous high fuel economy (km/L) should not be the criterion (see discussion in Subsection 4.1.10). Besides, an SFC feedback is informative in that it provides insight to how and why fuel economy is increased from a change in a driving habit.

3.3.3/ Condition for SFC Minimization

SFC can be used freely as a guide in fuel-economical driving since, to a large degree, the total energy expenditure in transient driving does not depend on the torque schedule. In other words, it matters little how the vehicle is accelerated and road grades negotiated because the external energy expenditure in travelling from A to B is the same as long as the chosen driving technique does not lead to extra braking either by the engine (motoring) or by applying brakes. (External energy expenditure here covers acceleration, coping with elevation differences, and overcoming the air and rolling resistance.) The kinetic energy increment in any acceleration depends only on the levels of the initial and final velocity and not on the manner of acceleration. Even if the driver, at any point on his trip, accelerates to a higher speed than conditions warrant, the excess energy expenditure is not lost if he then slowly decelerates to the proper, lower speed. The excess kinetic energy will have been used to overcome the road load.

3.3.4/ Fuel Economy According to SFC

With a transmission featuring a large range of gear ratios extending into high overdrive, driving fuel-economically according to SFC feedback would be simple:

- For any driving situation choose a gear that requires a relatively heavy trottle (high torque).

In reality, almost all commonly available manual transmissions provide only a limited amount of overdrive and one will simply have to accept the cruise SFC that the top gear yields. (High overdrive cars from Germany are just now starting to appear on the market.) Opportunities for minimizing SFC arise over the transient trip segments, sandwiched between the steady cruise trip segments, which occur with a fairly high frequency in city and suburban driving. The transients include varying road grade, adjustments to traffic conditions, speed changes and acceleration from a stop.

The fact that the total energy supplied to the driving wheels, the external energy, is relatively independent of a transient driving schedule, as discussed above, means that the maximum fuel economy can be achieved

simply by minimizing the average SFC over a transient trip segment. In the process, the length of the transient trip segment will vary somewhat, extending more or less into the steady cruise trip segment.

As observed before, cruise almost always occurs at a higher than minimum SFC, making it desirable to stretch out any transient driving situation which can be performed at a lower SFC (i.e., the acceleration should take place at somewhat below the minimum SFC engine loading). Similarly, transient operation over a trip segment imposes an engine loading which is sometimes higher and sometimes lower than the cruise engine loading. The lowest average SFC under these conditions is achieved when the SFC variation is minimized. The reason for this is the strongly nonlinear variation of the SFC with engine loading at a given RPM (a detailed discussion of this is beyond the scope of this report). How this concept is applied to the fuel-economical driving practices is discussed under Function in Subsection 4.1.10.

3.4/ Commentary on Driving Practices

This subsection provides the rationale behind each of the fuel-economical driving practices listed in Table 1.

1A/ Acceleration with Manual Drive

The advice to accelerate at somewhat below the minimum SFC engine loading still means a high engine loading and fairly brisk acceleration. Referring to Figure 1, this implies that the throttle must be increased steadily with RPM to maintain engine loading and a low SFC.

However, in most cars this produces a higher level of acceleration in lower gears due to torque multiplication than most drivers appreciate. Thus, the tendency is to let the engine unload and slide into the high SFC region (it is very easy in the lower gears to let the vehicle acceleration outpace accelerator depression and for the engine to rev up lightly loaded). These drivers should learn either to accelerate faster or else to upshift at a low engine speed of 2000 RPM or less with a fuel-injected engine and perhaps a somewhat higher RPM with a carbureted engine. Acceleration should be controlled

through shift-point speeds and not by the throttle. The throttle simply maintains the engine properly loaded.

1B/ Acceleration with Automatic Drive

The automatic transmission shift points are set to occur at relatively high engine RPM letting the engine rev high in the lower gears. To prevent light engine loading and consequently high SFC, it is advisable to accelerate briskly (moderate engine loading) at the beginning of an acceleration in the lower gears where torque multiplication is high and to back off acceleration as vehicle speed picks up.

From computer simulation [7] the acceleration in the top gear must be low for maximum fuel economy. A zero-to-60 km/h acceleration run was simulated at different levels of acceleration (followed by a short constant-speed cruise to cover an equal total distance at all levels of acceleration and to allow comparison). The lowest consumption occurred when the acceleration rate varied from 2 m/s^2 initially to less than 0.3 m/s^2 at the end of acceleration (essentially a constant throttle process). This gave fuel economy 12.4% better than the worst case which occurred at a constant acceleration of 1.5 m/s^2.

This leads to the overall recommendation to accelerate at a constant throttle of approximately 50%.

2/ Short Grades

Cruising over short grades, over hills and hollows, should take place at more or less constant throttle, resulting in some slow-down on up-grades and speed-up on down-grades. The main concern is to keep away from power enrichment on one hand and engine motoring on the other. The SFC is poor at light loads and some acceleration on a down-grade makes fuel-economical sense. Deceleration on the uphill side allows acceleration on the down-hill side.

3/ Long Ascent

When cruising up a long grade, it is advisable to establish the vehicle speed corresponding to the highest reserve torque. This is near

the region of the lowest SFC on the SFC map and allows ascending the steepest grade without getting into power enrichment. However, if power enrichment is reached, it should be used freely. It is one of the driving situations for which power enrichment was designed.

On a long downgrade, coasting in neutral would save fuel and is legal in Ontario. However, it is not recommended with an automatic transmission where the fluid coupling already exhibits considerable slip when the engine is being motored and where one can conceivably overshoot the shift and end up in reverse.

4/ Cruise Speed

The economical cruising speed (in top gear) falls in the range between 50 to 90 km/h (30 to 55 mph). Below 50 km/h, the road load falls off rather slowly and the SFC increases rapidly. Above 90 km/h, the road load starts to increase rapidly. The recommendation is to cruise at the highest speed that traffic permits without exceeding 90 km/h. If going with the wind, the economy range extends to a higher vehicle speed.

As noted in the previous subsection, the top gear on virtually all automobiles is not nearly high enough to load the engine sufficiently under normal cruising conditions to maintain a near-minimum SFC yielding the best possible fuel economy.

5/ Avoid Power

Fuel-air mixture richness is carefully controlled over the normal engine operating range to achieve the leanest possible mixture richness, and lowest fuel consumption, consistent with driveability and emission control. The driver can contribute to fuel economy only by avoiding low manifold vacuum and the attendant mixture enrichment.

When the throttle is opened beyond the point where the manifold vacuum drops below 3 to 7 in. Hg (depending mainly on the power-to-weight ratio of the vehicle) the air-fuel mixture is progressively enriched by a maximum of around 20% to increase the the available power. The power increase, however, is less than proportional and

the SFC increases as well. Hence, using near full throttle should be reserved for situations where it is truly needed.

6/ Avoid Pumping the Accelerator

Depressing the accelerator pedal with a carbureted engine will actuate the accelerator pump piston and squirt approximately 1 to 2 mL of gasoline into the carburetor with each full stroke [1]. This is useful for rapid engine pick-up when the throttle is opened and in cold-weather starting where engine stall can be avoided by pumping. However, if such activation is done unnecessarily or excessively it leads to fuel wastage.

7/ Avoid Erratic Driving

Erratic driving as a result of over-eagerness to make headway in congested or tightly-controlled traffic or as a result of failing to pay attention to the road and traffic ahead is generally felt to be one of the chief causes of poor fuel economy [1]. It can lead to light loading (high SFC) and revving of the engine due to poorly controlled gear shifting, activation of the acceleration pump and unnecessary braking either by motoring the engine or by applying the brakes.

8/ Utilizing Kinetic Energy

To make use of the considerable kinetic energy contained in a moving vehicle one should anticipate slow-downs and stops let up on the throttle and coast to a speed of around 40 km/h. This is a somewhat arbitrary figure depending on how much anticipation is possible, whether the vehicle has to slow down on an upgrade or downgrade, etc. It is given here to indicate that coasting to a lower speed than 40 km/h will save little fuel -- probably less than 1% in average driving. Also, it would be a waste of travel time for most people, and likely to interfere with traffic.

If the driver anticipates a slow-down or stop and lets up on the throttle to coast, the engine will use no more or only a little more fuel than at idle. An automatic transmission should be left in "Drive" for coasting (see item 3 above). A manual transmission could be left in the top gear or it could be shifted into neutral to eliminate engine motoring drag. In neutral, fuel saving should be highest

but the slowdown would be slow and may interfere with traffic.

9/ Minimize Idle

An idling engine delivers zero km/L while consuming enough fuel to propel the average 1970s car 1 km for every four minutes of idling [3]. The idle fuel flow is largely proportional to engine displacement and this is one reason cars with large engines give poorer city driving fuel economy than cars fitted with smaller engines. To minimize this wastage:

- warm up the engine by driving off moderately rather than by idling (except for the first 15 s or so to establish lubrication),
- shut off the engine when expecting to stand for an extended period.

Idle RPM has a significant effect on fuel economy as well as emissions. In fact, vehicle manufacturers are introducing schemes to reduce idle RPM. The only thing the driver can do here is to make certain a fully-warmed engine does not idle faster than specified. If it does, it should be adjusted by a knowledgeable mechanic.

3.5/ Special Controls

This subsection covers any other driver controls, besides throttle, gear shift and brake which affect fuel economy. At the present stage of vehicle development this includes only the choke.

Applying choke increases the mixture richness and is used when the engine is cold and fuel evaporation inadequate. This increases fuel consumption. Choke is set either manually or automatically. The manual choke should be kept on only as much and as long as needed using driveability as a measure of that need. A very useful driver aid device with the manual choke is a "choke on" signal, such as a light. It is considered a must. With an automatic choke, the only thing that can be done if it stays on longer than needed is to tap the accelerator. This will cause the choke to open as much as its control permits. Apart from its fuel economy penalty, excessive use of choke also causes undesirable engine oil dilution.

4/ DRIVER AID PARAMETERS AND DEVICES

The previous section covered fuel-economical driving practices, the basic vehicle operational concepts related to these practices, and the existing engine and transmission controls. This section addresses the various vehicle operational parameters that can be measured and used to assist the driver to exercise those practices, and the corresponding feedback or control devices. It also addresses devices that perform a specific driver aid function but are not associated with any particular vehicle parameter. All of these "monitors" have to interact with the existing vehicle controls.* The aim is to establish the potentially effective parameters and device concepts for real-time driving control. In the next section, a critical assessment and comparison will be made of the potentially effective devices discussed here.

In addition to the above real-time monitors, the section includes the indirect monitors which record the mentioned parameters and accumulate information. They can be useful in trip-making decisions and fuel-economical driving in general.

In listing the various monitors, at least a note will be made of all those known to have been considered in the past. Also, where there are gaps, suggestions will be made for new monitors. The development of the material involved extensive reviews of related literature.

4.1/ Driver Aid Parametric Monitors

This subsection covers an assessment of the vehicle parameters which relate to fuel-economical driving and the monitors which measure these parameters and communicate the feedback in proper form to the driver. Such parameters and their appropriate units include:

1/ Throttle, percent;
2/ Manifold vacuum, in. Hg;
3/ Vehicle speed, km/h;
4/ Engine speed, RPM;

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* The word "monitor" is used to denote not only measurement and observation, but also the control of a quality in relation to driver aid devices.

5/ Fuel economy (MPG) -- instantaneous or averaged over a time period, km/L;
6/ Fuel flow rate, L/h;
7/ Engine air flow rate, m^3/min;
8/ Vehicle acceleration, m/s^2;
9/ Exhaust gas temperature, °C;
10/ Specific fuel consumption (SFC), L/kWh.

The assessment includes a discussion of the parameter characteristics and, in physical terms, how the parameter relates to the operation of the vehicle and its components. When it obviously can serve as a meaningful feedback, feasible monitor concepts and configurations are presented. Thus, where appropriate, the assessment covers:

- functions,
- extraneous effects,
- device design criteria, and
- device concepts.

4.1.1/ Throttle

Discussion

Throttle, or accelerator depression, is a parameter. It controls the carburettor flow area and hence the pressure drop across it. With that it controls the manifold vacuum.

It should be noted that engine loading is not proportional to throttle. At a low RPM even a moderate throttle opening will result in a nearly atmospheric manifold pressure (low vacuum) and a high engine loading whereas at a high RPM engine loading tends to be more proportional to throttle. The correspondence is complicated also by the linkage arrangement converting accelerator depression into rotation of the throttle plate.

Functions

The usefulness of throttle as a monitoring parameter arises from certain driving practices requiring either a constant throttle setting or minimizing throttle actuation.

- Acceleration with automatic drive -- a feedback to maintain a constant throttle would offer a good solution.

- Short grades and erratic driving -- an adjustable throttle control for constant throttle cruise would satisfy the basic requirement.

These monitoring and control function opportunities lead to specific driver aid devices covered in the Subsection 4.2.

4.1.2/ Manifold Vacuum

Discussion

Manifold vacuum is the vacuum in the intake manifold referred to the ambient pressure and commonly expressed in inches of mercury (in. Hg). It indicates how much the manifold pressure is lower than the ambient pressure.

During the intake stroke, a piston draws a fresh charge of air and fuel into the cylinder. Largely because of the throttle restriction, and to a lesser degree the flow restriction of air filter and carburettor, there is always a vacuum in the intake manifold, i.e., the pressure is always below the atmospheric pressure.

The lowest manifold vacuum of near zero in. Hg occurs at wide open throttle when climbing a steep hill or accelerating at full power. This is true for all cars. In a typical car of the 1970s, climbing a moderate hill can be accomplished at 5 to 10 in. of manifold vacuum; moderate acceleration at 10 in.; cruise at 15 in. At idle, the throttle is almost closed and the engine draws about 18 to 20 in. of vacuum. The newer, lower power-to-weight ratio fuel-economical cars run at considerably lower vacuum levels (at a more open throttle under the same driving conditions).

Functions

1/ Manifold vacuum serves as an approximate indicator of fuel economy -- high vacuum, high economy. The combination of high vehicle (engine) speed and low engine loading (throttled flow and low fuel flow rate) results in high manifold vacuum and high km/L at the same time. This

feedback characteristic is useful when cruising at an economical speed (a lower speed results in a much reduced engine loading and a higher vacuum -- hence a higher economy, to a point).

It must be understood, however, that fuel economy is not an indicator of the engine or propulsion system thermal efficiency. In fact, it would give a wrong indication and should not be used as a guide in transient operation.

2/ A steady vacuum indicates a constant engine loading and requires maintaining a more or less constant throttle. It is the desired condition for the following driving practices:
- cruising over short grades
- avoiding erratic driving (starts usually with acceleration which registers as low vacuum/low economy).

3/ The lowest range of manifold vacuum gives a direct indication of mixture enrichment.

Extraneous Effects

The variations of ambient pressure affect manifold vacuum and at the same time maximum engine power as well as engine thermal efficiency. Ambient pressure varies from day-to-day and with elevation at a rate of 1 in. Hg drop for every 300 m (1000 ft.) elevation rise. In relation to the common automotive usage of vacuum gauge discussed here, two effects need consideration:

- For the same vehicle operating conditions, vacuum will be lower at a lower ambient pressure (higher altitude), but the fuel economy will actually be improved. This, however, should not be of much consequence since a vacuum gauge is used mainly as a qualitative indicator of fuel economy.

- Engine power enrichment is set to start at a certain vacuum and a vacuum gauge is a correct indicator of that. At a lower ambient pressure or a higher altitude, power enrichment is reached more readily but that does not change anything regarding the use of a vacuum gaug ine avoiding the power enrichment driving practice.

Device Design Criteria

1/ Since it is possible for a pressure measuring system to incur a considerable time lag, a maximum of 0.5 s time constant is suggested to assure an adequately fast response.

2/ The manifold vacuum corresponding to a vehicle operating condition can vary greatly with the vehicle make, model and year and depends on whether the vehicle has a manual or automatic drive. Thus, the vacuum levels corresponding to a given set of feedback signals or instructions should be different with different vehicles.

3/ Providing feedback on the actual level of the vacuum would let the driver in on what is happening and arouse his interest.

Device Concepts

1/ Common Automotive Vacuum Gauge

A diaphragm type pressure transducer where a change in pressure differential causes a needle to rotate around a pivot point describes the common vacuum gauge. It has been found to be the most effective gauge configuration for automotive use [15].

The following comments can be made regarding the appropriateness of such a vacuum gauge for the driver aid device application:

- It is a highly reliable device unless abused; the environment in the passenger compartment of a light duty vehicle is acceptable for high reliability.
- It is relatively simple to install.
- Its time constant is quite low; the response speed would depend mainly on the tubing size leading to the gauge.
- Even a relatively inexpensive gauge provides sufficient accuracy.

The automotive vacuum gauge display is usually designed to encourage operation at a high manifold vacuum. Also, the power enrichment range to be avoided is usually marked off. Alternatively, use instructions with vacuum gauges showing only in. Hg markings have been used with moderate success [2].

For the monitoring functions listed above, the recommended scale should include in. Hg markings as well as the power enrichment and deceleration range markings both of which should be vehicle-specific to inspire consumer confidence. Also, the indication of increased fuel economy in the direction of increased vacuum is expected to be useful.

2/ Vacuum Buzzer

The vacuum threshold buzzer has been developed to perform a very specific feedback function, i.e., to let the driver know when he is into the power range. Commonly, the buzzer is preset to sound off and flash a red light when manifold vacuum drops below a certain level. Several preset vacuum threshold levels are available and the buzzer can be de-activated by the driver. This configuration has proven to be effective [2] and no changes are suggested at this point.

4.1.3/ Vehicle Speed

Discussion

Vehicle speed feedback and control is part of over half of the fuel-economical driving practices. The usefulness of vehicle speed indication is enhanced by it giving a useful indication of engine RPM as well. Every vehicle is already equipped with a speedometer and for it to serve as driver aid it must be complemented with prompters and additional scale markings. The effectiveness of the speedometer as a driver aid device may be diminished by the fact that often it does not have a simple display and that its scale tends to be compressed. The 0 to 90 km/h portion of the scale, where most of the fuel-economy action takes place, occupies typically only one-half of the speedometer quadrant. Thus, any special driver aid markings on a speedometer dial must be compressed. A speedometer dial specifically designed for fuel-economical driving feedback could make the speedometer a considerably more useful device.

Functions

Vehicle speed can be used to indicate the following:

- The minimum speed for upshift in each gear when accelerating with a manual drive -- shifting at speeds lower than indicated would force the engine, after the shift, to operate below the low speed limit of the recommended operating range. That would actually incur an increase in fuel consumption and would result in a very low reserve torque increment as well. Thus, upshift indication is essential if one wants to improve fuel-economy by early shifting. The possible shortcomings of such an upshift scheme are that the driver has to be aware of the gear he is in and also, the shift speed depends to some extent on road grade.

- The best speed for ascending long grades -- which corresponds to the maximum torque reserve speed in top gear.

- Cruising speed economy -- possibly the most effective form of feedback would indicate the percent fall-off in cruise speed.

Device Concepts

The device suggested here consists of a set of graphic markings (symbols, numerals, colour shadings, etc.) which can be attached to the face of the existing speedometer. Since the upshift speeds tend to be strongly vehicle-specific, the speedometer scale marking positions must be known for all similar vehicle groupings.

4.1.4/ RPM

Discussion

RPM conveys less information than vehicle speed but, because it is specialized to the extent that it monitors only engine operation, it tends to be more useful. Also, as a special driver aid device the display can be optimized for driver aid feedback. Compared to the vehicle "speed device" the advantage of RPM appears to lie in its easy readability and less sluggish movement of the needle in lower gears. Also, it gives a

direct indication of engine operation as the prime mover. On the other hand, its usefulness may be somewhat diminished by the already-installed speedometer which, to some degree, can take its place.

Functions

An RPM feedback device can assume all the driver aid functions of the speedometer device listed above and essentially the same comments apply. The following comments point out the differences:

- The minimum shift speeds tend to fall on the same RPM in each gear. Consequently, the feedback is much simplified.

- The best RPM for ascending long grades applies to operation in top gear only.

- The cruising speed fuel economy variation (percent fall-off in fuel economy) would also apply to operation in top gear only.

In addition to these functions, the engine RPM range for efficient operation (low SFC), typically 1500 to 3000 RPM, can be indicated on the display.

Device Concepts

An RPM device could be entirely similar to a typical tachometer where RPM is measured exclusively now by connecting electronic circuitry to the distributor.

From experience, a large simple dial attracts attention. It would also facilitate the display of the various markings serving to prompt the driver. With a new RPM device the incorporation of warning lights and auditory prompters would also become feasible.

4.1.5/ MPG

Discussion

MPG, or fuel economy in km/L, is derived from a simultaneous measurement of vehicle speed and fuel flow. It is the direct measurement of fuel

economy which is always to be maximized over a trip and which relates directly to the fuel economy standards. Owing to this direct correspondence, the U.S. DOT in 1976 considered passing legislation to make the MPG meter mandatory equipment on new cars [17]. However, preliminary tests performed at that time, concluded that "It has not yet been demonstrated that the use of available MPG meters will improve fuel economy for the typical drivers".

The findings of the study lead to two observations:

- Driving involves much operation at transient conditions where it is difficult to relate fuel-economical driving to the MPG reading.

- In the absence of strong motivation, there is little potential for fuel saving on highways where fuel economy is in conflict with the natural tendency to drive fast. This is reflected in the low potential for fuel saving assigned to the driving practice advising the driver to drive at an economical speed.

Part of the problem can be traced to the fact that while the trip average km/L should indeed be maximized for fuel economy, in transient driving situations a high instantaneous km/L means fuel inefficient engine operation (Subsection 3.3.2 and 4.1.10) and should be avoided or moderated. The high km/L gives an appropriate indication only when coasting in anticipation of a slowdown and, of course, in steady state operation. The practical consequence is that an MPG meter should come with very good use instructions and be combined with other devices for maximum impact.

Functions

Much like the manifold vacuum, which is also an indicator of fuel economy, MPG can give some useful feedback with respect to a number of driving practices and, much like manifold vacuum, the feedback tends to be only moderately effective. It tends to encourage driving with a light foot.

First and foremost it allows the driver to establish unerringly the most economical steady cruising speed regardless of wind conditions and road

gradients or the state of any other vehicle or environmental variable. For that, however, it would be helpful to provide the driver the MPG average over some time period.

MPG is likely to be only a moderately helpful feedback in cruising over short grades, avoiding erratic driving, or in minimizing idle -- conditions where some time averaging is acceptable and perhaps even desirable.

In the more transient driving practices such as avoiding the power range and acceleration with automatic drive, the MPG feedback, even if very nearly instantaneous, cannot be particularly useful. There are simply too many factors involved (e.g., the vehicle is being usefully accelerated, and MPG is changing continuously) to know whether the reading is unreasonably low or not. Any excessive fuel use, therefore, tends to be masked.

Device Design Criteria

1/ The instantaneous MPG is quite sensitive to driving conditions, therefore time averaging would be useful for certain driving practices to blanket the transient variations. This would include "cruise speed" and perhaps "cruising over short grades" and "avoiding erratic driving".

2/ To be useful in certain other driving practices, the MPG response should be quick. That would include "avoiding the power range", "acceleration with automatic drive", and perhaps again "avoiding erratic driving".

3/ For an MPG reading to be useful as instantaneous it should have a lag of not more than 1 s. The U.S. DOT [17] in 1976 felt that "the lag of 1 to 10 s (of the then-available MPG meters) is not sufficiently quick to assist the driver". Stanford Research Institute [11] in 1976 considered the 4 s "averaging window" of the Zemco ZT-4 to be too broad for an instanteous feedback.

Device Concepts

There are four possible configurations between the instantaneous, or nearly instantaneous, and time-averaging MPG feedback and the analog and digital display. It is suggested that an updated time-averaged MPG feedback together with an "over" or "under" (the averaged value) indication might be the combination to be considered first. The averaging time period thus becomes a critical factor. Bendix is currently developing a meter displaying the "rolling updated average MPG". They have settled on an 8 min averaging period (the display always shows the average for the last 8 min). For the "over" or "under" indication, the best averaging time for that feedback has yet to be established although it is felt it should be relatively short.

The design of the device componentry is becoming pretty well established as exemplified by the Zemco ZT3 MPG meter. The fuel sensor uses the ball-in-race concept and the speed sensor uses stick-on-magnets (to be stuck on the drive shaft) and field sensor. Both of these components can be adequately accurate and highly reliable.

4.1.6/ Fuel Flow Rate

Fuel flow rate, usually measured in L/h or gal/h, has been promoted for fuel-economical driving [1] with the instruction "to adjust vehicle speed and/or acceleration to obtain minimum fuel flow rate consistent with driving condition or need".

Such promotion is ill-founded since there is no basis for it in either steady or transient driving situations. Fuel flow rate varies very broadly in normal driving and it alone can not be related to fuel efficiency or fuel economy in a meaningful way. Fuel flow rate would, however, provide a useful reminder to the driver that idling is wasteful.

4.1.7/ Air Flow Rate

Engine air flow rate is very nearly proportional to fuel flow rate except in the power enrichment range. Similar to the fuel flow rate, it is not a useful driver aid parameter, although it has been promoted as such.

4.1.8/ Vehicle Acceleration

There are two ways of determining vehicle acceleration. Each fares differently as a driving aid monitor.

1/ Acceleration from differentiating vehicles speed vs. time -- this gives the true linear acceleration along a roadway, i.e., speeding up and slowing down. Monitoring of vehicle speed change in this manner is not useful in any transient situation where acceleration rate with both the manual and automatic drives depends strongly on terrain and vehicle speed. Similarly, fuel-economical constant throttle cruise results in unpredictable variations of speed. Thus, overall, this monitor does not appear to provide any readily usable feedback.

2/ Acceleration from an inclinometer, which automatically includes gravity effects of road grade. For example, in a constant throttle cruise upon reaching an up-incline vehicle velocity starts to drop but measured acceleration/deceleration remains essentially zero. Since the inclinometer measures the instantaneous variation of engine loading it gives an indication of throttle variation (or else speed variation at constant throttle). Similar to Item 1 above, the usefulness of the inclinometer feedback appears minimal in transient situations except as an indicator of erratic driving.

Owing to the apparent low effectiveness of accelerometers as driver aid devices they will not be covered in any detail. However, the inclinometer type accelerometer will be included in the cost-effectiveness assessment below.

4.1.9/ Exhaust Gas Temperature

Devices for measuring exhaust gas temperature have proven helpful in determining engine efficiency and fuel economy on diesel trucks. They have been made available also as add-on equipment for automobiles [1, 17].

Exhaust gas temperature is primarily a function of engine power or fuel flow rate and varies strongly more or less in proportion to those parameters. Similar to fuel flow rate, temperature cannot be recommended as a feedback for fuel-economical driving.

4.1.10/ Specific Fuel Consumption

Discussion

The concept of propulsion system SFC was discussed in Subsection 3.3.1. It expresses the amount of fuel consumed to produce 1 kWh of useful mechanical energy.

As noted, SFC is commonly plotted in the form of constant SFC lines on a grid of BMEP or torque vs. RPM. For driver aid purposes, the SFC contours could be mapped on a grid of manifold vacuum vs. RPM, two readily measured parameters which have already been discussed. Such use of manifold vacuum is considered an important feature of a potential device in that the map could be displayed to the driver from readily measured input.

The eng. ? and driveline losses in given gear are uniquely defined by mainfold vacuum and RMP and likely the same mapping would apply regardless of which gear the transmission is in.

Besides SFC, the map could display certain information given on both the RPM feedback device (upshift points, best speed for ascending long hills) and the vacuum gauge (power range, deceleration range). Also, it could accurately display the constant km/L lines for operation in top gears.

One potential source of confusion should be clarified at this point. As noted under Functions in Subsection 4.1.2, the higher the manifold vacuum, the higher the fuel economy (km/L), but the higher also the SFC which indicates a low engine efficiency. This apparent discrepancy can be clarified by noting, by way of an example, that holding enough throttle to maintain the cruise speed down a short grade assures a low fuel flow while the vehicle is covering much ground and giving an exceptionally high fuel economy. At the same time the SFC is very high because fuel is being used largely to rev up the engine and cover pumping losses with little useful power output.

The question is, "Are we being efficient or not?" The answer is, "No!" The aim should be to minimize the trip average SFC as discussed in Subsection 3.3.4. The instantaneous fuel economy tells us how many kilometres are we getting per litre; SFC tells us how efficiently we are using that litre of fuel.

At this point in time, the concept of an SFC map device will not be advocated. It is presented here to point out a gap in providing the driver useful feedback and to indicate a possible opportunity. More research, including some preliminary testing is required to prove the concept. While the effectiveness of an SFC map device can only be surmised, it would appear to have a strong appeal in providing highly informative feedback to the driver.

Function

SFC can be used as an effective feedback in all transient driving situations. It can also usefully monitor unusual steady driving conditions such as ascending a long grade. As noted in Subsection 3.3.4 for the highest overall fuel economy, any low SFC opportunity should be stretched to cover a portion of the adjacent trip segment that in itself would be at a higher SFC.

This is done by:

- always shifting into the next higher gear as soon as possible, thereby lowering the acceleration, and/or

- backing-off somewhat from the lowest SFC locus on the SFC map which would only minimally increase the instantaneous SFC but improve the average over a given distance.

Both of these practices result in lowered acceleration and somewhat increased trip time but assure the lowest trip average SFC and consequently the highest trip fuel economy.

If trip time is more important than maximum fuel-economy, transient driving could be accomplished by following closely the minimum SFC locus and shifting at an RPM where the SFC begins to increase significantly -- around 3600 RPM in Figure 1. The trade-off is a small loss of fuel economy.

The average SFC over a trip should be minimized on an energy basis. This means that the level of SFC is more important during high power operation than during low power operation. Since at moderate engine speeds high power (high engine loading) goes together with low pumping losses and consequently a low SFC, there is a basis for achieving a low trip-average SFC without too much difficulty. The trick is to know when and how to load the engine. That becomes a matter of proper SFC feedback and good instructions. The specific functions of the SFC device, the specific form of the feedback, and the detailed instructions with respect to each of the driving practices have yet to be optimized and should be the subject of another study.

Extraneous Effects

This topic will be proposed for a future study.

Device Design Criteria

This topic will be proposed for a future study. Let it be only noted here that the SFC map may be strongly vehicle-specific and the manual and automatic transmission versions are certain to differ significantly.

Device Concepts

1/ SFC Map

Because of the informative nature of the SFC map it would appear most effective to display it for visual feedback. The SFC map device could assume the form of a rectangular or polar two-co-ordinate display with the cursor position corresponding to RPM on one co-ordinate and to manifold vacuum on the other. Overlaid on the display could be propulsion system SFC contours and, optionally, other markings and ranges similar to those appearing on the vacuum gauge and RPM meter. The ranges on the vacuum gauge become regions on the SFC map.

A number of options are open in selecting the device components and arranging its configuration. While the output from the distributor would be processed electronically to give RPM, either a mechanical or electrical pressure transducer could be used for the vacuum. Either an all-electronic display or a mechanically moving bar-column, or some other arrangement could be used for the visual feedback. Lights and auditory signals could be added as prompters (e.g., upshift indication, avoiding power range).

2/ SFC Vacuum Gauge

Since on an SFC map the constant manifold vacuum and constant SFC lines run more or less parallel to each other, one could take the average vacuum values in the usual RPM working range of, say, 1500 to 3000 RPM and use them for an SFC scale on a vacuum gauge. That scale could be displayed alongside other scales commonly used on a vacuum gauge.

4.2/ Specific Function Driver Aid Devices

This section covers those devices designed to perform a specific driver aid function. The potentially effective device concepts, either existing or derived from a well-defined need, include:

1/ upshift indicator,
2/ cruise control (automatically maintained constant vehicle speed as set by driver),
3/ throttle control (automatically maintained constant throttle as set by driver),
4/ throttle feedback (an aid to establishing a predetermined throttle position for constant throttle acceleration),
5/ acceleration pump monitor,
6/ idle reminder.

The first four of these devices are covered below in turn, including a description and comments on design and effectiveness.

4.2.1/ Upshift Indicator

Background

In Subsection 3.4, Item 1A, the point was made that fuel-economical acceleration with a manual transmission would require a much higher acceleration level than most drivers would appreciate. Instead of training the driver to accelerate briskly one could, as a compromise solution, prompt him to shift at a low RPM. That would not be as effective as brisk acceleration but certainly more so than letting the engine rev up lightly loaded.

The prompting could be done by marking the vehicle speed points corresponding to the low RPM shift points on the speedometer or by installing a tachometer with the low shift speed point marked (only moderately effective solutions because of the lack of positive prompting). A shortcoming of such markings is that there is no indication of whether the acceleration is adequately brisk (and fuel efficient) to allow it to proceed to the higher RPM levels.

An upshift indicator overcomes all these shortcomings by providing prompting for an early shift when the acceleration is low and by doing it more forcefully by means of a special upshift indicator light.

Until now, the drivers of manual transmission cars have shifted by feel, using engine noise and vibration and perhaps wind noise and throttle feel as guides, and having little idea how their shifting habits affect fuel economy. The introduction of the shift indicator by Volkswagen is the first attempt to fill that gap. The objective is to shift engine operation closer to the maximum torque limit where the SFC is lowest.

As an interesting aside, the original purpose of the VW upshift indicator may have been to convince EPA that the upshift points in the EPA fuel economy tests, which are prescribed to occur at 15, 25 and 40 mph with a 4-speed manual transmission should be car-specific and in the case of the VW gasoline Rabbit should occur at 9, 18 and 29 mph. These much lower shift speeds would significantly improve fuel economy. However, it has been difficult to convince the EPA that the drivers indeed use the indicator to good effect.

Concept

In Volkswagen's approach (information gleaned from a VW internal report) the prime monitoring parameter is the upshift RPM. To avoid the high RPM/low engine loading condition, the lowest shift RPM was specified that would:

a/ allow the FTP-Cycle (EPA City Cycle) to be followed over the most critical portion of the cycle regarding vehicle performance, and

b/ assure sufficient reserve power after an upshift to operate the vehicle adequately over the "typical U.S. acceleration profile" (acceleration vs. vehicle speed plot established by VW of America, Inc. from data available in the U.S.).

The other monitoring parameter is manifold vacuum which constrains the upshift indicator to come on only when the vacuum is above a predetermined level, i.e., only at the lower levels of acceleration where the engine SFC is high and an upshift would provide a significant gain in fuel economy. At the higher levels of acceleration, the indicator would not come on because the engine is operating more efficiently and shifting would bring less benefit.

The practical consequence of this is that when the indicator light does come on it does so at a very low engine speed -- at 1850 RPM with the gasoline Rabbit (2300 RPM with the Diesel Rabbit), -- and that takes some getting used to. It also means that after the shift the engine speed drops to around 1300 RPM, a very low speed indeed for acceleration. But the driver need not be concerned. The engine is fuel injected and the cyclinder-to-cyclinder fuel distribution does not suffer. Also, modern engines have high pressure lubrication and high engine loading at low RPM is acceptable.

To complete the picture, the indicator is de-activated in top gear where low engine loading, high RPM operation can readily be encountered. Also, it incorporates a throttle idle position de-activation switch, presumably to keep the indicator light off during fast idle.

Design and Effectiveness

The upshift indicator is a device of average complexity. There are two control switches -- one a vacuum switch operated by manifold vacuum and the other activated by electrical impulse count from the ignition coil. When both switches are closed and manifold vacuum and RPM are both above certain levels, the upshift indicator comes on. Another two switches de-activate the indicator when the transmission is in top gear or when the throttle is on idle.

The indicator light is installed at the lower half of the instrument panel on the centreline where, according to VW's surveys, its placement is fully acceptable by the users. Also its brightness has been adjusted to be acceptable.

According to VW, the increase in City Fuel Economy from the use of the individual shift points for the 1.7 L K-Jetronic fuel injection gasoline Rabbit is 8%. Over the EPA Composite Cycle the fuel saving potential from the use of this device would be around 4%.

Improvement Potential

The design philosophy of the upshift indicator is to let the driver accelerate at the level he is used to. A possible improvement to that concept is to provide another light which comes on simply when the vacuum is too high prompting the driver to use more throttle. It would be for the benefit of those drivers who do not mind changing their driving habits to get the full fuel economy gain.

4.2.2/ Cruise Control

Cruise control allows the driver to preset a desired cruising speed. Through a servo-actuator, the device then automatically adjusts the throttle to maintain that speed. The driver can release the unit or override it by touching the brake or by pressing down on the accelerator.

The biggest advantage of the device as a driver aid for fuel economy is that it helps to avoid erratic driving. It should be useful in maintaining an economical cruising speed where the set speed is expected to be lower on the average than the speed constantly manipulated by the driver. With the device there may be less tendency to cruise beyond a moderate speed. However, the device's effectiveness is diminished somewhat by maintaining a constant speed and not constant throttle under varying terrain and road conditions. A serious detriment to its use is its high price. Nevertheless it is included in the effectiveness evaluation in Section 6.

4.2.3/ Throttle Control

Throttle control is a new application of an existing device which was in use some time ago. It would let the driver set the throttle at any desired position much like the hand throttle in older cars. The driver could override it by the accelerator, or release it by touching the brake.

Throttle control would provide the desired constant throttle for cruise over short grades and help to maintain an economical cruising speed and to avoid erratic driving. Also, it would make cruising more pleasant and less tiring to the driver.

No specific hardware configurations are suggested here but the design could be a modification of some existing hand throttle configuration.

4.2.4/ Throttle Feedback

The fuel-economical way to accelerate with a conventional automatic transmission is to maintain a constant throttle in the 45 to 60% range until a moderate cruising speed is reached in the top gear. A device is suggested that would aid the driver to find and maintain that throttle setting every time he accelerates. The feedback could be sensory, auditory, or make use of indicator lights, but it should be adjustable to allow for the variability among cars. Also, some flexibility may have to be built into it to compensate for variations in road grade.

4.3/ Indirect Monitors

Three types of indirect monitors are used as driver aid devices:

- Totalizers
- Fuel economy averaging
- Trip recorders

4.3.1/ Totalizers

A totalizer displays the total amount of fuel in litres consumed on a trip or over a part of a trip. Alternatively, the corresponding total fuel cost in dollars is displayed.

It has been suggested that awareness of the trip fuel cost will provide a driver sufficient motivation to modify his trip-making habits to conserve fuel, at least in situations where the amount of fuel used is not commensurate with the importance of the trip. An example that has been cited is a short trip to the store to buy a convenience item involving a winter-time cold start which consumes an unreasonably large amount of fuel compared to the length of the trip.

However, verbal communication with James McKnight of the National Public Service Institute, Alexandria, Virginia, indicated otherwise. The Institute has performed a test installing totalizers in a group of cars serving to discourage the making of marginally useful trips. Their tests showed that indeed the average driver takes many short trips ranging from 1.5 to 5 km but is not willing to reduce the number of short trips even when made well aware of the trip cost as a regular feedback. The attitude of the small car owners in particular was that they already had reduced their overall fuel consumption by buying a small car and now they are entitled to the convenience of using it whenever a need is there. The cost of gasoline is simply not a factor at the current fuel prices.

Still, it would appear that knowing the trip fuel consumption or fuel cost would result in some fuel saving. An interesting comparison could be made of the work trip fuel cost variation with traffic, weather, and route selection. There is a possibility that such information will have some influence on trip-making decisions and result in fuel conservation.

The other use of trip fuel consumption feedback would be in a systematic assessment of the effect of a driving skill improvement over a marked distance (short trip). However, not many drivers are likely to get involved in such an assessment and the impact from this use of the device will likely be minimal. The trip fuel consumption feedback cannot be considered a driver aid parameter providing straightforward, action-oriented signals [1].

4.3.2/ Fuel Economy Averaging

The trip-average fuel economy, km/L, can be used to give an indication of the day-to-day fuel economy impact from changes in driving habits or in the operating condition of the car such as tire inflation or tune-ups and installation of snow tires or a roof rack. Like the totalizer above, it can be moderately useful in the hands of an alert and interested driver but it is not expected to have a significant impact on the total fuel consumption of the average driver.

4.3.3/ Trip Recorders

Recording either in the analog or digital form every few seconds to a minute a set of instantaneous vehicle operating parameters including vehicle speed, engine RPM, manifold vacuum, and fuel consumption has been used to monitor the operation of fleet trucks. Such recorders tend to be expensive (in the order of $1000) and the records have to be processed and analysed through special procedures. Such recording is not a practical way to improve fuel-economical driving of the average driver. However, recorders can be used profitably in test driving designed to prove the effectiveness of driver aid devices.

5/ EFFECTIVENESS AND COST-EFFECTIVENESS

In this section, the device effectiveness, fuel saving and cost-effectiveness tabulations are developed based on the above material and on a review of previous test results (a review of testing and test results is covered in the next section). These tabulations apply to selected generic device types.

5.1/ Effectiveness Tabulations -- Single Devices

This subsection covers the assessment of generic devices when used singly in conjunction only with the standard speedometer. Specifically, it contains the following:

- A listing of the generic devices to be included in the effectiveness assessment along with a brief description of each device for ready reference (Subsection 5.1.1).

- Comments on control feedback, control action, and on device effectiveness tabulated against each of the fuel-economical driving practices as listed in Section 3. This is done for selected generic devices or control parameters on which device concepts are based. In all assessments a device is assumed to incorporate proven effective feedback schemes, either visual, auditory and sensory, or a combination of these. Also, the effectiveness is predicated on well-developed use instructions supplied with the device (Subsection 5.1.2).

- A summary tabulation of effectiveness and cost-effectiveness. The unit and installation costs are based on representative prices in Canadian stores and on a review of the reported installation costs in the U.S. Cost-effectiveness is expressed in terms of benefit-cost ratio derived from the net present value assessment outlined in Appendix A (Subsection 5.1.3).

It must be emphasized that the driving practice effectiveness figures and the totalized device effectiveness figures have been compared at every stage with available data from a number of sources and by-and-large they are in line with those data.

5.1.1/ Listing of Generic Devices

1/ Vacuum Gauge

A dial type (analog) vacuum gauge marked in in. Hg with power enrichment and motoring ranges set off. Visual.

2/ Vacuum Buzzer

Vacuum threshold buzzer preset to sound off and flash a red light when power enrichment becomes significant. Auditory and warning light.

3/ Vehicle Speed

Speedometer (analog) with markings for (a) shift speeds, (b) maximum torque reserve speed, (c) percent fall-off in cruise fuel economy from maximum. Visual. Not marketed.

4/ RPM

An RPM feedback device (analog) with same scale markings as the speedometer above. Visual. Not marketed.

5/ MPG

A fuel economy meter displaying either (a) instantaneous km/L (analog or digital) or (b) updated average km/L (analog or digital) and (+) or (-) deviation from average. (Preliminary tests have shown the analog and digital to be equally effective.) Visual.

6/ Acceleration

An inclinometer type gauge (analog). A specific feedback form is not suggested, however a visual display type is the most common.

7/ Upshift Indicator

A light to prompt early upshift at low levels of acceleration. Visual.

8/ Cruise Control

Adjustable control to maintain a set cruise speed. The control can be overridden.

9/ Throttle Control

Adjustable control to maintain a set throttle. The control can be overridden.

10/ Throttle Feedback

A feedback aiding the driver to maintain a constant throttle during acceleration. Sensory, auditory or visual.

11/ SFC Vacuum Gauge

A dial type (analog) vacuum gauge similar in every respect to the common automotive vacuum gauge except that a scale representing the propulsion system specific fuel consumption is added. Visual.

12/ SFC Map

A two-co-ordinate display with cursor position corresponding to RPM on one co-ordinate and manifold vacuum on the other. Overlaid on the display are the propulsion system SFC contours and other markings similar to those appearing on the vacuum gauge and on RPM meters. Visual.

A number of the above devices should be specific to the vehicle. The only device which has been made specific to some degree is the vacuum buzzer which is available at several preset vacuum threshold levels.

For the purpose of overall effectiveness/cost-effectiveness assessment. the control feedback and driver action appropriate for each specific driving practice is presented next for selected parametric monitors.

5.1.2/ Comments on Selected Devices

Refer to Tables 2, 3, 4, 5.

5.1.3/ Summary Tabulations

Refer to Table 6.

6/ DEVICE SELECTION AND COMBINATION

The purpose of the above summary tabulations is three-fold:

- to establish the absolute and relative cost-effectiveness of the devices;
- to serve as a basis for the selection and recommendation of devices for evaluation, testing and demonstration; and
- to get an indication how the devices complement each other.

While several new devices have been suggested to fill gaps, the selection will have to include only those devices on the market. Exceptions are made for:

- the vehicle speed device because its implementation would involve minimal expense and no hardware development,
- the RPM meter (for the same reason), and
- the upshift indicator because it is already available as a standard item on a new car (VW).

If and when the other new devices become developed, they can be readily assessed and the favourable device combinations selected within the evaluation framework of this report.

6.1/ Existing Devices

Below, the existing devices which are available either off-the-shelf or in the basic form needing some modification or as original equipment on new vehicles are arranged according to their cost-effectiveness expressed in terms of benefit-cost ratio (Appendix A). The cost-effectiveness figures are given after each device for the manual (M) and automatic (A) drives.

1/ Vacuum gauge	(M)1.5/(A)1.8	-- high
2/ Vehicle speed device	1.7/1.1	-- high
3/ Vacuum buzzer	1.3	-- high
4/ Accelerometer	1.1	-- medium
5/ Upshift indicator	0.9/ -	-- medium
6/ RPM meter	0.9/ -	-- medium
7/ MPG meter	0.5/0.6	-- low
8/ Cruise control	0.3/0.3	-- low

When attempting to sort out the cost-effective devices, it should be kept in mind that the fuel saving and the installed device cost figures making up the benefit-cost ratios are estimates. These ratios could change significantly and, along with that, the relative order of devices. In particular, if the installed cost of the MPG meters sold in Ontario would come down, they might eventually prove cost-effective.

Certain devices complement each other making it possible to achieve overall fuel economy improvements and, in some instances, more nearly the maximum potential of a driving practice.

When considering device combinations it should be noted that the MPG meter fairly duplicates the function of a vacuum gauge and one could replace the other with little change in effectiveness.

The relatively cost-effective combinations in order of decreasing cost-effectiveness include:

• Vacuum gauge and vehicle speed device	for (M)	-- high
• Vacuum gauge and vacuum buzzer	for (M) or (A)	-- high
• Vacuum gauge and upshift indicator	for (M)	-- medium
• Vacuum gauge and RPM meter	for (M)	-- medium

An MPG meter could be combined effectively with exactly the same set of devices. However, here the cost-effectiveness would range from medium-low to low.

A couple of notes are in order.

Firstly, it would appear that combining the vehicle speed device with either the vacuum gauge or MPG meter would overload the driver -- the vehicle speed device requires a fair amount of concentration on its own.

Secondly, the vacuum buzzer could be readily incorporated into a vacuum gauge or vice versa at only a small increase in cost. This would add perhaps one percentage point to the potential fuel saving for planning purposes from the vacuum gauge while maintaining its cost-effectiveness.

6.2/ Off-the-Shelf Devices

Of the off-the-shelf devices available, only three merit consideration at the present time. The accelerometer is not of particular interest because its functions could be performed equally well with a vacuum gauge which is a more useful device and more cost-effective. The cruise control is too costly and certainly not cost-effective. This leaves:

- vacuum gauge,
- vacuum buzzer, and
- MPG meter,

all of which are more or less effective with both manual and automatic drives.

While all of them could be used singly, it would be beneficial to combine:

- vacuum gauge and vacuum buzzer, and
- MPG meter and vacuum buzzer.

Tests by Bendix [2] indicate that the MPG meter either alone or in combination with the vacuum buzzer is somewhat more effective than the vacuum gauge in similar configurations. However, Bendix used a straight vacuum gauge with an in. Hg scale which is difficult to use as a prompter and therefore their test may not be conclusive.

From the device summary tabulations in Table 6, it is obvious that among the off-the-shelf devices there are none that can effectively aid the driver in acceleration, either with manual or automatic drives.

7/ REVIEW OF TESTING AND TEST RESULTS

7.1/ Types of Tests

A good estimation of the potential and in-use effectiveness of driver aid devices can be obtained from driver tests where the fuel economy with a device (device test run) is compared to the fuel economy without the device (baseline test run).

Such tests must be run in sufficiently large numbers to arrive at statistically valid results. The baseline fuel economy and the fuel economy gain from changes in driving habits both vary greatly among drivers. Also, if more than one vehicle is used, it must be borne in mind that the fuel economy of well-tuned identical vehicles can vary as much as 5 to 10%.

Two types of tests are common -- controlled road tests and field tests.

7.1.1/ Controlled Road Tests

The first road tests of a device should be performed under controlled conditions of little or no traffic, dry pavement and low wind velocities to establish the potential effectiveness of a device. Controlled road testing is considered an extension of laboratory testing and an essential part of the assessment and R & D of a device.

To account for all the variations in driving conditions, it would be highly useful to install a trip recorder in the vehicle for the baseline and device test runs. This would give an indication of traffic interference as well as any changes in driving habits which then can be related to a fuel economy gain. With a trip recorder, it would be quite feasible to run tests in some well-chosen city/suburban test route at off-peak traffic conditions.

7.1.2/ Field Tests

A "field test" refers to the use of vehicles in day-to-day driving to establish the in-use effectiveness of a device. Vehicles are run first

without the device and then with the device installed. This would demonstrate the ability of the average driver to gain fuel economy from the use of a device. Either a relatively short-term test could be prescribed, or the test could be designed to establish the long-term effectiveness in actual use and the possible effectiveness fall-off.

At the present time, in a field test, there is no easy way to monitor how a vehicle is used in actual driving or the variations in environmental conditions encountered by a specific vehicle. Thus such tests are conducted on a large scale. Many vehicles must be involved because of the large variance in fuel economy among drivers (and vehicles) and the large day-to-day scatter of any data associated with vehicle driving. The ability of a driver to make effective use of a device has been shown to vary greatly as well. A baseline vehicle group using no devices must be set up in the same geographical area to provide the day-to-day baseline variation, making it possible to factor out the external/environmental variations. Device test runs must be preceded by baseline runs by all vehicles involved.

As a result, such tests are costly to manage. It makes sense to undertake a field test only once the potential effectiveness of a device has been established.

A field test could be made much more meaningful and the required number of vehicles reduced if a simple totalizing recorder were installed in the vehicle. It could record, say, for each day the following:

- total number of engine starts,
- total number of stops,
- total idle time,
- total distance travelled,
- average speed,
- average acceleration below and above a certain vehicle speed,
- total time spent in coasting, and,
- total amount of fuel used.

Each of these quantities relates to the fuel economy of the vehicle and can be readily totalized.

7.2/ Test Procedures and Practices

7.2.1/ General

The following procedures and practices are recommended for both controlled road tests and field tests and are used here as the criteria in assessing the usefulness of previous test results.

1/ Select representative vehicle(s) -- year, make, model, engine specifications, driveline specifications.

2/ Specify vehicles without air conditioning to eliminate an element of variability.

3/ Assure that vehicles are in proper tune at the start and end of the test.

4/ Assure driver familiarity with the vehicle before data runs; using driver's own vehicle is recommended.

5/ The same driver should do the baseline and device test runs.

6/ Calibrate the tested devices at least before testing to assure accuracy over the critical regions of operation.

7/ Make certain the drivers have been provided the intended instructions -- no more, no less (the quality of the instructions and any extra information supplied with the instructions can considerably infuence the outcome of tests).

8/ Test should be run under moderate climatic conditions, certainly above the freezing temperature.

9/ Cold tire pressure should be maintained constant during testing.

10/ Assure minimal variation of fuel energy content (API gravity) during testing.

7.2.2/ Controlled Road Tests

1/ Assure minimal duty cycle (driving pattern) variation unless the vehicle is equipped with a test recorder and the effects of such variation on the results can be adequately quantified. This would not be a problem on a test track or with simulated traffic but, on any in-use road, interference can be significant -- even with very light traffic.

2/ Minimize variation of vehicle operating conditions -- vehicle weight, window opening, etc.

3/ Engine and tires should be fully warmed -- approximately 15 minutes of running at over 60 km/h prior to data runs.

4/ Run only when pavement is dry and winds are low.

5/ Repeat each run a sufficient number of times to establish an adequate statistical description of the result.

7.2.3/ Field Tests

1/ Automobile fuel economy testing is notorious for scatter of data and a new device introduced into the driver's environment is likely to make it even more so [12]. A minimum of 10 vehicles in each test group (identical treatment) appears necessary in closely monitored testing to establish a few percent improvement in fuel economy.

2/ Both fuel purchase records and fuel flow measurement should be used to establish fuel consumption and to minimize the possibility of great confusion caused by a false reading. This means that a fuel flow totalizer should be installed in all test and control vehicles regardless of the specific device to be tested.

3/ The distance in kilometres travelled should be recorded by the driver and independently in some other way.

4/ For purposes of data analysis it would be highly useful, but perhaps impractical, for the driver to record the road condition, wet or dry, and wind strength, low, medium or high.

5/ When the purpose is to establish the long-term effectiveness of a device, testing must cover a period of several months for the novelty of the device and its challenge to wear off. Most of the learning and training is expected to occur over the first few weeks of device use.

7.2.4/ Other Considerations in Device Testing

Along with the above test procedures and practices, the following items should be given consideration in the design of the test and in determining the usefulness or validity of test results.

1/ A test could cover either the manual or automatic transmission vehicles. If both are included, the results should be segregated because the impact of a device can depend strongly on the transmission type.

2/ Separation of results according to urban and highway driving would be informative and useful in implementing a device.

3/ If possible, fuel economy gain should be compared to the driver's individual baseline fuel economy standing. Such a correlation is useful in establishing the potential of a device attributable to a driver's driving skills, and in the implementation of a device. (According to MTC tests [8], the baseline fuel economy of the worst driver can be 50% higher than that of the best driver using the same vehicle, and the measured improvement from a driver aid device by the worst driver tends to be much higher.)

4/ The question of when is the best time to provide information feedback to the driver regarding his fuel economy gain has not been resolved; improper action here may have an extraneous effect on the result.

7.3/ Review

The results of three major, relatively recent test studies are reviewed here in detail. They have been performed to establish the potential for fuel economy improvement from the more popular driver aid devices on the market. All three investigations have been performed in the U.S. and were supported by government. They include:

- Driver Aid and Education Test Project, Nevada Operations Office, U.S. DOE, 1978 (DOE Field Test).

- Driver Feedback Device Evaluation Experiments, Bendix Corporation for U.S. DOE, 1981 (Bendix Road Test).

- Testing of MPG Meters and Vacuum Gauges on Car Driver Performance, Stanford Research Institute, International, for California Energy Commission, 1982 (SRI Field Test).

The review is based largely on the recommended test procedures and practices developed in the previous subsection.

7.3.1/ DOE Field Test

The purpose of the test was to assess the fuel economy gain achievable from the different types of vacuum gauge devices, a driver training course and a combination of these measures.

7.3.1.1/ Test Design

1/ Specifically, the following driver aid items were tested:
- a dial-type vacuum gauge, a Stewart-Warner Motor Minder (dial marked, "poor", "fair", "good", and "deceleration");
- a piston-type vacuum gauge, Vac Tach brand;
- driver awareness training course;
- the dial-type vacuum gauge in combination with a training course.

2/ Two test groups were involved:
- the highway test segment of the DOE working fleet vehicles, 70% pick-ups, 30% compact and intermediate size cars; these vehicles were divided into five groups of 87 vehicles each (one group serving as the control group);
- the urban test segment of the Clark County working fleet vehicles divided into five groups of 22 vehicles each.

With the highway test segment, 80% of vehicles were one vehicle/one driver assignments, 20% of vehicles one vehicle/several driver assignments. With the urban test segment, assignments are not known.

3/ Test duration was 16 months -- 8 months of baseline runs of generally decreasing ambient temperatures followed by 8 months of trial runs at generally increasing ambient temperatures. Thus, the average temperature was the same for each test sequence.

4/ All vehicles included in the test were classified according to size and weight, transmission type and air conditioning option.

5/ A locking gas cap was installed in each vehicle with the key controlled by the driver assigned to that vehicle. Fuel was supplied through three service stations located on the test site. Independent log books were maintained by the driver and the attendant.

6/ No feedback was provided to the drivers regarding fuel economy gains by any of the vehicles during the test period.

7.3.1.2/ Results

1/ The following average fuel economy gains were posted over the 8-month trial period:

	Hwy	Urban	Avg.
• Training only	3.4%	4.5%	4.0%
• Dial vacuum, no training	3.5	5.5	4.5
• Piston vacuum, no training	3.9	-2.4	0.8
• Dial vacuum plus training	5.3	1.9	3.6

2/ The greatest improvements in fuel economy occurred early in the treatment phases and decreased over the remainder of the phase.

3/ Significantly, there was a considerably more positive overall response to the dial-type vacuum gauge than to the piston-type vacuum gauge.

7.3.1.3/ Comments

1/ The quality of the driver awareness training course and the instructions provided with the vacuum gauge are not known.

7.3.1.4/ Conclusions

1/ There is little to criticize in this investigation as a field test except that no tangible incentives were provided. The roughly 4%

fuel economy improvement from the dial-type vacuum gauge can be taken as indicative of the magnitude of fuel economy gain possible in the private sector from this device.

2/ The piston-type vacuum gauge shows only a marginal fuel economy improvement for the average driver and should receive less consideration as a driver aid device.

3/ A training course offered simultaneously with the installation of a vacuum gauge does not appear to improve fuel economy over the use of the device supplied only with instructions for use.

4/ In this investigation, no motivation of any kind was provided to the driver. When compared to other studies where no gain was experienced despite the incentive of saving money, it must be concluded that, at least at the current fuel price levels, a saving in the fuel cost is not influential.

7.3.2/ Bendix Road Test

7.3.2.1/ Test Design

1/ The purpose of the test was to assess the following devices installed either singly or in various combinations:
- Flo Scan 660 instantaneous MPG, analog display;
- Price Crown 150 updated trip average MPG, digital display;
- Marshalltown vacuum gauge, circular dial, in. Hg scale;
- Gastell vacuum threshold buzzer.

2/ All testing was done on a rented 1981 Dodge Aries sedan. It is assumed that the car was equipped with an automatic transmission and had no air-conditioning.

3/ The test circuit was 14 miles long -- 9 miles urban road (30 traffic lights), and 5 miles highway (55 mph speed limit).

4/ Runs were made at off-peak hours in light traffic.

7.3.2.2/ Comments

1/ Tests were run in Denver, Colorado, apparently in spring and summer at moderate ambient temperatures. No information is supplied regarding weather and pavement conditions.

2/ The relatively long test runs would tend to reduce scatter and permit a smaller number of runs for an adequate statistical description.

3/ There is no indication of vehicle tune-ups.

4/ A vehicle warm-up drive of 10 min is considered somewhat short.

5/ An experimenter was accompanying each driver during testing -- not a normal driving situation, although it may not have mattered.

7.3.2.3/ Test Design (Experiment I)

1/ Sixteen drivers were participating, each making four test runs; a total of 64 test runs including the four baseline runs.

2/ There are 16 possible combinations of four feedback devices; a special test and data reduction procedure for handling the device configurations would, in effect, give a minimum of eight data runs for each device configuration.

3/ Testing covered a four-week period.

7.3.2.4/ Results (Experiment I)

1/ The average standard deviation for all test runs was approximately 5%.

2/ All device configurations (devices singly and in combination) showed a fuel economy gain. Depending on the configuration, that gain ranged from 1.0 to 5.0%, but without a clear consistency as to which combinations might be best.

3/ When used alone, the vacuum buzzer (3.0% gain) and the instantaneous MPG (2.6% gain) were marginally better than the other devices. The average MPG singly was most ineffective (1.0% gain), probably

because its indication of improvement rapidly becomes sluggish as distance accumulates. Vacuum gauge alone was also relatively ineffective (1.3%).

4/ According to the rating by drivers, combinations of two and three devices have the highest utility, indicating liking and perceived effectiveness (and perhaps the ease of relating feedback and reaction to a fuel economy change).

5/ Utility and understandability (clarity, simplicity) as perceived by the driver correlate well with the actual fuel economy gain.

6/ Voice delivery of the average MPG information, tested in a separate sequence, was least satisfactory of all devices in terms of perceived utility and understandability.

7.3.2.5/ Comments (Experiment I)

1/ Baseline was apparently the first run only in one test sequence. This permitted three out of four drivers some familiarization with driving skills improvement before running a baseline.

7.3.2.6/ Conclusions (Experiment I)

1/ The fuel economy results are inconclusive with no clear indication as to which device configurations are the best. Such an indication may have been obscured by the following:

- The limitations of the devices are not well established and the use of instructions not sufficiently well developed. Consequently, device use is subject to at least some individual interpretation.
- The learning effect was not considered (from the results of Reference 12, a certain amount of randomness of fuel economy gain is experienced initially).
- Traffic may have significantly influenced the results.

2/ Considering the inadequate and partly misleading device use instructions it is felt that the fuel economy potential of some devices (vacuum gauge, MPG meters) could possibly not have been achieved.

3/ Most of the fuel economy gain can probably be achieved with a combination of two devices, one of them being the vacuum buzzer.

4/ Evaluations of the understandability and perceived utility of a device indicate that good feedback design and first-rate use instructions are essential.

5/ Any auditory feedback has to be designed with great care to be acceptable in terms of annoyance.

6/ Drivers found the digital display entirely acceptable; also, preliminary results show a digital display to be effective.

7.3.2.7/ Test Design (Experiment II)

1/ This experiment was designed to evaluate five selected driver feedback device configurations consisting of two devices each. These were:

- average MPG and vacuum buzzer,
- instantaneous MPG and vacuum buzzer,
- vacuum gauge and voice average MPG,
- vacuum gauge and average MPG, and
- instantaneous MPG and voice average MPG.

2/ Fifteen drivers were participating, none of whom had partaken in Experiment I; however, some had experience in fuel-economical driving before.

3/ The test sequence included one baseline trial and three learning trials by each driver. Only one device configuration was assigned to each driver.

4/ Following the completion of the baseline trial by the 15 drivers, they all were briefed in fuel-efficient driving in general and the nature and functions of the five different feedback devices to be evaluated.

5/ The urban and highway fuel consumptions were measured separately.

6/ Fuel economy gain data on each driver was disseminated to all drivers throughout the test sequence.

7.3.2.8/ Results (Experiment II)

1/ The mean average MPG gain for all five device configurations was 5.5% for the three trials and 7.5% for the last two trials, considering the first trial as familiarization. However, for the three learning trials, the traffic was heavier than for the baseline trial.

2/ Differences among the device configurations fell short of significance.

3/ Urban and highway fuel economy gains went hand-in-hand.

7.3.2.9/ Conclusions (Experiment II)

1/ The instructions provided with the devices and at the driver training session are good, except for the advice on acceleration. In contrast, the instructions provided in Experiment I were relatively poor. This should at least partially account for the larger fuel economy gain in Experiment II.

2/ Providing the instructions on fuel-efficient driving along with the device use instructions means that two influences were introduced at the same time. This renders the device assessment meaningless since the effectiveness of driver training alone has been shown to yield a fuel economy gain roughly equal to that from a device.

3/ Regardless of how achieved, the sizeable fuel economy gain is all the more important because of the heavier traffic during the trial runs and the partly incorrect advice on acceleration.

7.3.3/ SRI Field Test

7.3.3.1/ Test Design

1/ The purpose of the test was a relatively large-scale evaluation of the effectiveness of an MPG meter and a vacuum gauge in improving vehicle

vehicle fuel economy performance. Specifically, installation included:

- a VDO Vacuum gauge, circular dial with graduations in in. Hg and the low vacuum range below 9 in. Hg emphasized as something to be avoided.

- a Zemco ZT-4 digital "instantaneous" MPG meter, readings representing the average MPG over the last 4 s.

2/ The test was conducted with personal vehicles driven by owners.

3/ Five matched vehicle groups were assembled, all 1979 models:
- two groups with manual drives: Honda Civic, Toyota Pick-up;
- three groups with automatic drives and air-conditioning: Chevrolet Monza, Oldsmobile Cutlass, Ford Fairmont.

4/ Each group included nominally 24 vehicles:
- 8 vehicles -- 9 months control baseline;
- 8 vehicles -- 6 months baseline, 3 months with vacuum gauge;
- 8 vehicles -- 6 months baseline, 3 months with MPG meter.

5/ Each vehicle owner kept track of fuel use (recording each purchase), mileage, and tire pressure.

6/ The only inducement to make good use of the installed device was fuel saving by the driver.

7/ Some separation of results according to urban or highway driving was designed into the test by selecting three predominantly urban groups and one predominantly highway group.

7.3.3.2/ Results

1/ No statistically valid fuel economy gain was observed from the devices.

2/ From an observation of graphically presented results, there is an indication of an initial gain from the vacuum gauge on the automatic transmission Ford Fairmont and some longer-term loss with both the vacuum gauge and MPG meter with the manual transmission Honda Civic.

7.3.3.3/ Comments

1/ The test design was not, perhaps, as rigorous as it could have been. Some erroneous reporting of fuel use and miles to fill-up could have occurred because of complete reliance on the driver in this regard.

- Tire pressure checks were not performed rigorously, only on cold tires.

- There was no monitoring of vehicle use -- the very low and very high weekly fuel economy results were discarded.

2/ The number of vehicles in each group was too small considering the fairly large scatter of data (standard deviation in the range of 10 to 15%).

3/ The device use instructions were not good, containing some erroneous and misleading information, particularly on the vacuum gauge. No separate instructions for the manual and automatic drive vehicles were provided.

7.3.3.4/ Conclusions

1/ The result of no indicated improvement could at least partially be attributed to the combination of:

- complexity of the chosen devices in their intended use providing no simple prompting and the fact that they are difficult or impossible to use in transient driving situations; and,

- relatively poor device use instructions.

2/ With the fuel economy potential of either device not clearly established through laboratory and controlled road tests, it was not proper to conduct a true field test.

3/ Apparently, a true field test allows too many variables to influence fuel economy and may be feasible only if some monitoring can be done as discussed in Subsection 7.1.2.

4/ The results of the test are significant in that this seems to be the only major test which avoided any training, advice, or peer group pressure to influence device use.

7.3.4/ Huntley/DOT Evaluation of MPG Meters (1976)

This U.S. DOT-sponsored evaluation of MPG meters involved 10 cars tested at the Transportation Systems Centre and 146 cars tested by the Automobile Club of Southern California. The test results (which should be considered preliminary), did not show any significant fuel economy gain for typical drivers. Nevertheless, the quantitative findings provide insight into the limitations of the MPG meter:

- In transient situations, the driver cannot make the most effective use of an MPG meter.
- In city driving, the driver cannot give much attention to an MPG meter.
- An MPG meter is useful in one-third of all mileage, that which is driven on rural highways.

7.3.5/ Summary

7.3.5.1/ On Testing

1/ Device test results should always be very carefully reviewed to establish their validity and extract useful information. Testing by a reputable agency does not guarantee the quality of results.

2/ The large divergence of results from the different tests indicates a need for better understanding of certain devices and for establishing the fuel economy potential of a device first. There is a strong tendency to simply take what is there and perform a large-scale test on it.

3/ Road testing needs to be controlled more rigorously, possibly with the help of a trip recorder.

4/ Field testing should not be undertaken until the potential effectiveness of a device has been proven under controlled conditions. A true field test with private vehicles allows too many variables to influence fuel economy and may be feasible only if the driving conditions are monitored, at least to some degree. Field tests are expensive to manage.

7.3.5.2/ Results

1/ When supplied along with reasonably good use instructions, the vacuum gauge and the MPG meter can both give a 3 to 5% fuel economy gain by the average driver after the initial period of learning and challenge. A similar gain is achieved from training in fuel-economical driving practices alone.

2/ A vacuum buzzer alone gives 2 to 3% improvement on a compact car.

3/ At the fuel prices in effect during the tests, fuel cost saving alone does not appear to provide an incentive of any consequence.

4/ The form of the feedback is very important. A device should be relatively easy to understand, informative, offer simple correspond ence between prompting and driver action, and be free of annoyance.

5/ Digital displays are acceptable and appear effective, at least with certain feedback.

6/ Selected devices can be combined to good effect. With the tested devices, the maximum effect is achieved with two devices.

8/ AVAILABLE DEVICES

This section covers an evaluation of the driver aid devices available on the market. Only those off-the-shelf devices are included which have been recommended for further consideration on the basis of this study (i.e, the vacuum gauge, vacuum buzzer and MPG meter). In the evaluation, considerable use is made of the results of previous investigations.

8.1/ Vacuum Gauge

Only the circular dial vacuum gauge is covered here.

8.1.1/ Functional Components

The 2.5 inch (diameter) vacuum gauge is the basic size for driver aid application. It has a standard accuracy of ± 0.6 in. Hg in the range from 6 to 24 in. Hg of vacuum and + 0.9 in. Hg outside that range. Its quality of construction can range from the standard quality level at $6 for a gauge (1000 unit lot) to industrial quality level at $8 for a gauge featuring an all-brass movement.

Large pressure oscillations and mechanical vibrations can reduce the life of a vacuum gauge considerably, but measuring the manifold vacuum in a light-duty road vehicle (a relatively favourable environment), a life in excess of 5 years can be expected.

In sum, it appears that all the 2.5-inch driver aid vacuum gauges would provide adequate accuracy, reliability and durability.

8.1.2/ Feedback

The scale markings are most important in selecting a vacuum gauge. As noted in Subsection 4.1.2 under Device Concepts, it would be advisable to display the in. Hg markings along with the power enrichment and deceleration range markings. In this respect the VDO vacuum gauge is good. The Gas Master vacuum gauge features an adjustable scale to permit partial accommodation to different vehicles but the gauge is complicated and does not function well. However, no other vacuum gauge was found that would feature adjustable markings or availability of different scale ranges to make it vehicle-specific.

8.1.3/ Packaging

The criteria should be compact size, unobtrusive mounting and ease of installation without special tools or skills. The common mounting location is on the steering column but dash mounting might be preferrable requiring minimal shifting of gaze from the road. The VDO vacuum gauge is particularly good in that respect as well [11]. Packaging includes also the night illumination.

8.1.4/ Availability

The cost of the 2.5-inch driver aid vacuum gauge starts at $19.95 for the MakeWaves unit sold at Canadian Tire Stores. The VDO vacuum gauge would sell for about $65, but there is no reason why a similar well-designed and constructed unit could not sell for about $25.

All the vacuum gauges available in Ontario are made in the U.S.A.

8.2/ Vacuum Buzzer

The main functional component in the vacuum buzzer is the pressure switch which shares subcomponents with the vacuum gauge. Comments on the vacuum gauge regarding accuracy, reliability, and durability apply in general also to the vacuum buzzer. The only vacuum buzzer found on the market is made by Gastell in the U.S. and distributed in Canada through Vancouver. Retail price is about $50. It contains a buzzer which can be de-activated and a warning light, and the unit is offered in four preset models specified for 4-, 5-, 6- and 8-cyclinder engines.

8.3/ MPG Meter

8.3.1/ Functional Components

The fuel sensor is mounted in the fuel line just ahead of the carburetor. It is easy to install. The ball-in-race sensor has become prevalent and tests by Bendix and Transport Canada indicate that it can be accurate and reliable.

Vehicle speed can be measured by means of stick-on magnets and a field sensor installed on the driveline output shaft (Zemco). With some other units (Prince Crown) the speed pick-up is mounted by means of a special

adapter at the transmission. Both designs are reliable and relatively easy to install. In contrast, the Floscan 660 speed sensor, which also attaches at the transmission, is more difficult to install requiring about 5 h by a knowledgeable mechanic.

The processor, along with the control unit, processes the signals from the fuel flow sensor and speed sensor together with the time from an internal clock and generates output for any of the various functions.

8.3.2/ Feedback

Feedback can be presented to the driver as fuel economy in km/L, fuel flow rate in L/h, trip fuel consumption or cost, average trip fuel economy, updated average fuel economy over a time period, fuel economy deviation from an average, etc. Again, as previously noted, the specific information provided by the feedback is most important -- as is the form of it, either analog or digital or a mix. Also, warning lights and auditory prompting can be incorporated. Unfortunately, the most effective functions and their form have not yet been established.

8.3.3/ Packaging

The comments made in relation to the vacuum gauge apply here as well.

8.3.4/ Availability

From evaluations by Transport Canada, Bendix [2], and Stanford Research Institute [11], the best MPG meters in terms of ease of calibration, accuracy and reliability appear to be the Crown 150 and Zemco ZT4. The Crown unit is available from Prince Corporation, Windcrest Drive, Holland, Michigan 49423, and the Zemco unit from Performance Improvements Speed Shops Ltd. in Toronto. Both cost around $150 (Can.). There are no Canadian-made MPG meters on the market.

9/ DEVICES AND IMPROVEMENTS BY VEHICLE MANUFACTURERS

Significant improvements in driveline design and fuel-economical engine/transmission control, which have been under development by vehicle manufacturers, are starting to come on line. These can impact substantially on the recommended practices for fuel-economical driving and on the need for and effectiveness of add-on driver aid devices. They can also influence MTC actions regarding the promotion of the devices.

Several car manufacturers in Ontario were contacted to establish which such improvements will be offered on new vehicles in the foreseeable future.

The information supplied by the manufacturers is presented below in the form of a list, largely without specific references. All the items listed impact on vehicle fuel economy and relate directly or indirectly to fuel-economical driving practices and hence the use of driver aid devices.

1/ **Upshift indicators** for the manual transmission are already available on Volkswagen cars. Several other manufacturers are planning to introduce the device. Depending on its level of sophistication it can, in the hands of a conscientious driver, impact significantly on fuel economy.

2/ **Lock-up torque converters** (split torque path automatic transmissions) have been in use with larger engines for several years. The device is in the development stage for four-cylinder front wheel drive applications. The mechanical lock-up reduces torque converter losses and allows efficient acceleration at higher engine loading levels or lower levels of manifold vacuum.

3/ **Electronically-controlled shift logic** is currently under development. It would establish the most fuel-economical gear for any level of acceleration. The driver could be further aided in selecting the most economical level of acceleration.

4/ **High overdrives** are being introduced by several manufacturers. This will make driving by SFC more effective.

5/ **Freewheeling** is available by Volkswagen with the E-mode automatic transmission where the drive between the transmission and differential is disengaged whenever the accelerator pedal is released. The car will freewheel on deceleration and at idle (allowing a lower idle speed) because the transmission will be in "neutral". With this feature, the driver can utilize the kinetic energy of the vehicle fully and make anticipation of slowdowns and stops an even more significant fuel saving measure.

6/ **Deceleration fuel shut-offs** allow the driver to decelerate using the engine for braking while consuming no fuel at all. It will be standard on some U.S. models in the 1983 model year and is expected to become available in Canada subsequently. It is available here already on some fuel-injected cars. Shutting off the fuel flow into the carburettor during deceleration can make coasting in gear even more fuel-economical than coasting in "neutral".

7/ **Lowering idle RPM** and, thus, the idle fuel consumption by controlling accessory loads and introducing refinements to the engine. With this, the driver needs to be less concerned with the idle engine switch-off.

8/ **Idle engine switch-off devices** are under preliminary investigation. One scheme would use flywheel energy storage for restart when the accelerator pedal is depressed after a stop.

9/ **MPG and fuel consumption** instrumentation is available on the more expensive cars and no doubt will become available on the lower priced cars. Their fuel economy effectiveness will depend on what functions are displayed and on the quality of the use instructions supplied with them.

In summary, the improvements fall into four categories:

- Automatic transmission loss reduction, overdrive extension and more flexible shift point control. This will improve fuel economy in acceleration with the best economy occurring at higher levels of acceleration. It will also improve cruise fuel economy.

- Higher overdrives for manual transmissions, providing more potential to exercise fuel-economical driving skills.

- More fuel-economical engine control in deceleration and idle, making fuel saving from coasting more attractive and concern with fuel loss from idle less significant.

- Introduction of selected driver aid devices -- upshift indicator and MPG meter.

The point has also been made that with the increased use of an on-board computer to control the basic engine parameters (spark timing, fuel rate, etc.) the devices which depend on computers will also become less costly.

The implications to MTC are:

- There is a clear need to keep abreast of the new developments, to assess their impact, and re-assess opportunities through the use of driver aid devices.

- The general importance of the devices is not expected to diminish. There will, however, be shifts in emphasis -- less opportunity in some areas, more in others.

10/ CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions and specific recommendations are made regarding the material covered in this report. These are distinct from the action plan for MTC for a systematic test/demonstration program.

10.1/ Driving Practices

1/ The fuel saving potential from a full adoption of the fuel-economical driving practices compiled here is estimated at 24% for a relatively alert, motivated driver starting from the fleet average fuel economy levels and assuming fully effective driver aid devices and instructions for use. The amount of fuel saving for planning purposes is assumed to be half of the above figure, i.e., 12%. These fuel savings would not be obtainable with the existing devices.

2/ Fuel-economical vehicle acceleration practices with the manual and automatic transmissions differ considerably and so do the device configurations applicable to these practices.

3/ Closely controlled dynamometer and/or road tests are recommended to verify the fuel economy gain from the acceleration practices recommended here and to establish sensitivities (fall-off in gain with deviation from the best practice). These tests should be run on representative cars (both manual and automatic transmissions).

4/ The specific recommendations for all the fuel-economical driving practices need more study to establish them well and validate the potential fuel saving figures. Emphasis should be placed on their application to the newer, lower power-to-weight ratio vehicles with both manual and automatic drives. This has not been done in any systematic way before.

5/ A series of specifically-designed tests could be run on the basis of this report to establish the best device for each driving practice. At the present time, there is no information available on this.

10.2/ Driver Aid Devices -- General

1/ For a device to be truly effective it should be either:

- very simple, providing on-off type auditory, visual or sensory feedback (e.g., vacuum threshold buzzer, upshift indicator), thus interfering minimally with the driver's vision or concentration; or

- simple and informative, relating explicitly to vehicle operation.

For the driver's benefit, it is essential to establish a definite understandable correspondence between a feedback signal, a change in driving habit, and fuel economy gain. Such a correspondence is badly lacking in the majority of devices on the market (e.g., vacuum gauge, MPG meter, accelerometer).

2/ Regardless of the feedback scheme, the annoyance factor must be removed (certain sound and voice feedbacks have been found annoying).

3/ From actual driving tests it has been established that a driver spends about 5% of his time looking at the instruments in city driving and 10% in highway driving. This indicates that there is scope for increased use of visual instrumentation at the expense of a few percent reduction in the amount of time absorbed in outside-oriented vision (90 to 95% of time).

4/ The use instructions provided with many devices are often misleading or erroneous, and minimally informative. This applies in particular to the vacuum gauge and accelerometer but it is also true to some extent for the MPG meter. The instructions should be rewritten based on a realistic correspondence between the device function and fuel economy gain. Such instructions may be presented in two parts -- the essential instructions and the back-up information. First-rate, attractively presented instructions are essential to get the driver involved, and understanding is the key to continued reinforcement.

10.3/ Driver Aid Devices -- Generic

1/ The common automotive vacuum gauge is an approximate indicator of fuel economy (km/L). This is moderately useful in establishing an economical operating speed. It gives a direct indication of mixture enrichment. Also being highly sensitive to throttle variation, it provides useful feedback when cruising over uneven terrain and in avoiding erratic driving. However, a vacuum gauge is not an indicator of engine efficiency and therefore of minimal use during transient operation. It is cost-effective -- expected fuel saving 4%, benefit/cost 1.6.

2/ The vacuum threshold buzzer, indicating the onset of power enrichment, has proven to be an effective device because of the simplicity of feedback and directness of required response. It is cost-effective -- expected fuel savings 2 to 3%, benefit/cost 1.2.

3/ An MPG meter does not provide simple prompting except in steady state cruise. Driving involves much operation at transient conditions where an MPG indication has little meaning and can be misleading (in transient conditions the efficient operation of the propulsion system and avoidance of deceleration are of primary concern and a high instantaneous fuel economy does not mean a high trip fuel economy). Nevertheless, controlled tests have demonstrated the MPG meter to be moderately effective when displaying the updated time-averaged MPG along with a more instantaneous "over" or "under" (the averaged value) indication. At current prices, it is not cost-effective -- expected fuel saving 4%, benefit/cost 0.6.

4/ Upshift indicator is for the manual transmission cars where it can be useful to those who tend to accelerate at a low rate. It prompts the driver to upshift at the lowest speed which assures adequate reserve power after an upshift. With that, the engine is kept operating relatively efficiently at a high loading (low SFC). It is marginally cost-effective -- expected fuel saving 3%, benefit/cost 0.9.

5/ Cruise control is not a cost-effective fuel economy driver aid device -- expected fuel saving 2.5%, benefit/cost 0.3.

6/ Throttle control would let the driver set and maintain the throttle at any desired position to avoid erratic driving, cruise at an economical speed, and negotiate short grades fuel-economically. This would be a new application of a device which was in use some time ago. It may be only marginally cost-effective if its usefulness as a cruising aid is not considered -- expected fuel saving 2.5%, benefit/cost 1.1.

7/ A throttle feedback device is suggested here that would aid the driver in accelerating with an automatic transmission using the proper amount of constant throttle every time. It appears to be cost-effective -- expected fuel saving 3.5%, benefit/cost 1.9.

8/ Currently, there are no aftermarket devices available to aid the driver with acceleration either with manual or automatic drives.

10.4/ Device Selection and Combinations

1/ The only off-the-shelf cost-effective devices are the vacuum gauge and the vacuum buzzer. The accelerometer is not recommended because its function could be performed with a vacuum gauge which is a more useful and cost-effective device. The MPG meter is somewhat less than cost-effective but has more glamour and the consumers may still be willing to buy it.

2/ Among the off-the-shelf devices, there are none that can effectively aid the driver in acceleration, either with manual or automatic drives.

3/ Combinations of the vacuum gauge with vacuum buzzer and MPG meter with vacuum buzzer represent effective complementation. The vacuum buzzer could be incorporated into a vacuum gauge or vice versa at only a small increase in cost.

10.5/ New Developments

In the preparation of this report, which included contacts with the various Canadian and U.S. Government agencies, local governments, car manufacturers and research establishments, there was no indication of any innovative development of devices. The only developmental activity is the modication of the MPG meter readout by Bendix under U.S. DOE sponsorship (Section 11.2).

11/ NOTES FOR AN ACTION PLAN

11.1/ The Setting

A basic objective of the study is to establish what MTC could be doing to promote fuel conservation by the use of driver aid devices and to lay out the optional courses of action.

The findings show there is considerable potential for fuel saving by the average driver, but in actual use the devices now on the market tend to be only marginally effective. Several of these devices are not cost-effective.

A number of shortcomings were uncovered which should at least partially explain the poor showing of the currently available devices.

- Some devices on the market are ill-conceived (ineffective parameters are used) and one potentially effective parameter, the specific fuel consumption, has not even been considered.

- The information feedback to the driver and/or the form of the feedback tend to be inappropriate and confusing and the feedback is not simply related to driver actions. As a consequence, the driver cannot take full advantage of the device and is likely to lose interest. The fuel economy gain from the device drops with time.

- Instructions for use tend to be poor and/or erroneous and not adequately informative.

This state of affairs indicates a considerable scope for improvement and an opportunity for constructive involvement on the part of MTC, although no immediate significant implementation opportunity is apparent.

11.2/ Optional Courses of Action

1/ Run a fleet test and demonstration on proven cost-effective generic devices to get hands-on experience prior to a wider promotion. The vacuum buzzer belongs in this category.

2/ Consider potentially cost-effective devices where the full potential has not been realized because of:

- poor use instructions,
- easily corrected shortcomings in feedback (display),
- inconclusive test results.

Effect improvements and perform controlled road tests. Currently only the vacuum gauge qualifies.

3/ Assess and monitor any potentially effective device under active development but not yet cost-effective. The MPG meter belongs here.

4/ Assess the opportunity for Ontario development and commercialization of potentially cost-effective device concepts or device combinations. If shown cost-effective, MTC may want to expedite development. The vacuum gauge/vacuum buzzer combination belongs in this category, as do several new device concepts -- particularly those based on the specific fuel consumption feedback.

5/ A project is suggested to validate the fuel-economical driving practices of Section 3 and the fuel saving potential of each for the different vehicle groupings, including a segregation by manual and automatic drive. Actual vehicle tests are recommended. The results would help to firm up the effectiveness and cost-effectiveness figures for the various driver aid devices. Also, they would provide a sound basis for any driving practice advice given out by MTC.

6/ Establish, through a demonstration program, the effectiveness of the devices in training new drivers to drive fuel-economically.

Related to the Action Item 3 above, the MPG meter, although it is not currently a cost-effective device, is receiving a great deal of attention, particularly in the area of device/driver interface. Specifically, Bendix, as a continuation of their evaluation of a number of devices singly and in combination, is developing a modification of the MPG meter. The final report on that development is expected in August. Shortly thereafter, MTC should be able to acquire a prototype of the device configuration from the U.S. DOT for its own testing.

11.3/ Test Capability

Action Items 2 and 4 above involve road testing. Should MTC include either of these items in their action plan the first major activity for the Ministry is to form such test capability. Controlled road testing is recommended here, removing as many variables as possible while still presenting a fairly realistic scenario to the driver. This involves establishing:

- the best test routes (urban and highway);
- test procedures to minimize scatter of data;
- the most suitable test instrumentation;
- the possible use of trip recorders -- establishing the need and specifications for recording to permit the elimination of the extraneous (variable) effects of traffic and shifts in basic driving styles;
- proper statistical data analysis procedures;
- the baseline fuel economy of test vehicles;
- the fuel economy gain of at least one device to prove the test capability.

The baseline and proving tests should be run with both manual and automatic drive cars to establish the procedural differences.

The formation of this test capability is a sizeable undertaking. However, a similar capability would be required for the road testing of any automotive fuel economy measure in the real-life situation. At MTC, such measures would include fuel economy products (devices, lubricants, additives), alternative fuels, etc.

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Table 1/ Fuel Economical Driving Practices and the Potential Saving

Practice	Potential** Saving
1A/ Acceleration with MANUAL drive -- use a moderately high engine loading at 60 to 75% throttle*; increase throttle with engine speed and shift early to lower acceleration.	(6%)
1B/ Acceleration with AUTOMATIC drive -- use a constant throttle of 45 to 60% to reach top gear fairly fast while acceleration is tapering off.	(6%)
2/ Cruising over short grades (hills and hollows) -- avoid large variations of throttle and allow speed to decrease going up and increase going down.	(1%)
3/ Ascending long grades -- establish and maintain peak reserve power RPM.	-
4/ Cruise at an economical speed.	(2%)
5/ Avoid power enrichment, i.e., avoid high engine loading (the lowest range of manifold vacuum) at any RPM.	(2%)
6/ Avoid activating acceleration pump, i.e., minimize movement of the accelerator.	(1%)
7/ Avoid erratic accelerations and decelerations, i.e., operation outside the efficient engine operating range and unnecessary braking and gear shifting.	(4%)
8/ Utilize the kinetic energy of the vehicle -- anticipate slow-downs and stops and coast in top gear or "Drive"; brake from approximately 40 km/h.	(6%)
9/ Minimize idle time -- switch off engine to avoid prolonged idle.	(2%)
	(24%)***

*Throttle means "accelerator depression".

**Under favourable conditions with effective devices and instructions for use(see Section 3.1).

***This is the potential saving; the average driver is expected to achieve about half as much, i.e., 12% see Section 3.1).

Table 2/ Comments on the Use of the Throttle as a Driver Aid

Driving Practice	Control Feedback and Action	Effectiveness*
1A/ Acceleration MANUAL		-
1B/ Acceleration AUTOMATIC	Throttle feedback would aid in maintaining constant throttle.	(3)
2/ Short grades	A throttle "set" would aid/encourage cruising at constant throttle.	(4)
3/ Long ascent		-
4/ Cruise speed	A throttle "set" would discourage cruising at high speeds.	(2)
5/ Avoid power	A throttle "set" would discourage heavy throttle and operation in the power range during cruise.	(1)
6/ Avoid pumping	Throttle feedback and control would deter excessive accelerator movement.	(4)
7/ Avoid erratic driving	A throttle "set" would encourage constant throttle operation (probably not effective in stop-and-go traffic).	(2)
8/ Utilize K.E.		-
9/ Minimize idle		-

*4 = very high, 3 = high, 2 = medium, 1 = low, (-) = zero or N/A

Table 3/ Device Involvement and Effectiveness in Modifying Specific Driving Practices -- Vacuum Gauge (Common Automotive Type)

Driving Practice	Control Feedback and Action	Effectiveness*
1A/ Acceleration MANUAL		-
1B/ Acceleration AUTOMATIC	Low acceleration in top gear (> 40 km/h) encouraged by increased vacuum.	(1)
2/ Short grades	Lowered vacuum to discourage constant speed ascent; maintain vacuum essentially constant.	(2)
3/ Long ascent		-
4/ Cruise speed	Above 60 km/h high vacuum (low cruising speed) indicates high fuel economy.	(2)
5/ Avoid power	The lowest levels of vacuum (less than 3 to 7 in. Hg depending on vehicle) explicitly discourage use of power range.	(4)
6/ Avoid pumping		-
7/ Avoid erratic driving	Low vacuum discourages unnecessary acceleration (throttle variation causes large variations in vacuum).	(2)
8/ Utilize K.E.	Coasting shows up as high vacuum (high fuel economy); gauge does not provide prompting.	(1)
9/ Minimize idle		-

*4 = very high, 3 = high, 2 = medium, 1 = low, (-) = zero or N/A.

Table 4/ Device Involvement and Effectiveness in Modifying Specific Driving Practices -- Special Markings Overlaid on Speedometer

Driving Practice	Control Feedback and Action	Effectiveness*
1A/ Acceleration MANUAL	Shift points for fuel economy indicated for low levels of acceleration; (shift points should vary with grade).	(1)
1B/ Acceleration AUTOMATIC		-
2/ Short grades		-
3/ Long ascent	Peak reserve power speed indicated.	(4)
4/ Cruise speed	Percent fall-off in fuel economy with speed indicated.	(3)
5/ Avoid power		-
6/ Avoid pumping		-
7/ Avoid erratic driving		-
8/ Utilize K.E.		-
9/ Minimize idle		-

*4 = very high, 3 = high, 2 = medium, 1 = low, (-) = zero or N/A.

Table 5/ Device Involvement and Effectiveness in Modifying Specific Driving Practices -- MPG Meters

Driving Practice	Control Feedback and Action	Effectiveness*
1A/ Acceleration MANUAL		-
1B/ Acceleration AUTOMATIC	High MPG indication to encourage low acceleration in top gear.	(2)
2/ Short grades	Lowered MPG indication to discourage constant-speed ascent; maintain a nearly constant MPG varying little from cruise value.	(2)
3/ Long ascent		-
4/ Cruise speed	MPG display allows adjustment of speed for a low MPG.	(4)
5/ Avoid power	The very low MPG provides discouragement but power enrichment may be difficult to distinquish from "regular" acceleration.	(1)
6/ Avoid pumping		-
7/ Avoid erratic driving	Low MPG indication to discourage unnecessary acceleration.	(2)
8/ Utilize K.E.	Coasting gives a high MPG indication; however, meter does not provide prompting	(1)
9/ Minimize idle	Idle shows up as zero MPG.	-

*4 = very high, 3 = high, 2 = medium, 1 = low, (-) = zero or NA.

Table 6/ Summary Tabulation

Device Effectiveness							
		(Rating) [1]Potential Fuel Saving, %					
Driving Practice	Maximum Potential [2] (%)	Vacuum Gauge	Vehicle Speed	RPM Meter	MPG Meter	Acceler-ometer	Vacuum Buzzer
1A/ Acceleration MANUAL (M)	6	-	(1) 1.5	(2) 3.0	-	-	-
1B/ Acceleration AUTOMATIC (A)	6	(1) 1.5	-	-	(1) 1.5	(2) 0.5	-
2/ Short grades	1	(2) 0.5	-	-	(2) 0.5	-	-
3/ Long ascent	-	-	-	-	-	-	-
4/ Cruise speed	2	(2) 1.0	(3) 1.5	(3) 1.5	(4) 2.0	-	-
5/ Avoid power	2	(4) 2.0	-	-	(1) 0.5	-	(4) 2.0
6/ Avoid pumping	1	-	-	-	-	-	-
7/ Avoid erratic driving	4	(2) 2.0	-	-	(2) 2.0	(2) 2.0	(1) 1.0
8/ Utilize K.E.	6	(1) 1.5	-	-	(1) 1.5	(1) 1.5	-
9/ Minimize Idle	2	-	-	-	(2) 1.0	-	-
Total Potential Saving, %	(M)	7.0	3.0	4.5	7.5	4.0	3.0
	(A)	8.5	1.5	1.5	9.	4.0	3.0

Device Cost-Effectiveness [5]							
Saving for Planning Purposes [3]	(M)	3.5	1.5	3.0	4.0	2.0	3.0
	(A)	4.0	1.0	1.0	4.5	2.0	3.0
Cost Installed [4] (Parts + Labour)	$	50	20	70	170	40	50
	$	(30+20)	(5+15)	(50+20)	(130+40)	(30+10)	(30+20)
Benefit/Cost [5]	(M)	1.5	1.7	0.9	0.5	1.1	1.3
	(A)	1.8	1.1	0.3	0.6	1.1	1.3

(M) = Manual
(A) = Automatic

Table 6/ Summary Tabulation (Continued)

Driving Practice	Maximum Potential (%)	Device Effectiveness (Rating)[1] Potential Fuel Saving, % Upshift Indicator	Cruise Control	Throttle Control	Throttle Feedback	SFC Vacuum Gauge	SFC Map
1A/ Acceleration MANUAL (M)	6	(3) 4.5	-	-	-	(3) 4.5	(4) 6.0
1B/ Acceleration AUTOMATIC (A)	6	-	-	-	(3) 4.5	(1) 1.5	(2) 3.0
2/ Short grades	1		-	(4) 1.0		(2) 0.5	(2) 0.5
3/ Long ascent	-		-	-		-	-
4/ Cruise speed	2		(2) 1.0	(2) 1.0		(2) 1.0	(3) 1.5
5/ Avoid power	2		-	(1) 0.5		(4) 2.0	(4) 2.0
6/ Avoid pumping	1		-	-		-	-
7/ Avoid erratic driving	4		(3) 3.0	(2) 2.0		(2) 2.0	(2) 2.0
8/ Utilize K.E.	6		-	-		(1) 1.5	(1) 1.5
9/ Minimize Idle	2		-	-		(2) 1.0	(2) 1.0
Total Potential Saving, %	(M)	4.5	4.0	4.5	-	12.5	14.5
	(A)	-	4.0	4.5	4.5	9.5	11.5
Device Cost-Effectiveness[5]							
Saving for Planning Purposes[3]	(M)	3.0	2.5	2.5	-	6.0	7.5
	(A)	-	2.5	2.5	3.5	4.5	6.0
Cost Installed[4]	$	70	180	50	40	50	100
(Parts + Labour)	$	(40+30)	(120+60)	(30+20)	(20+20)	(30+20)	(80+20)
Benefit/Cost[5]	(M)	0.9	0.3	1.1	-	2.6	1.6
	(A)	-	0.3	1.1	1.9	2.0	1.3

(M) = Manual
(A) = Automatic

Footnotes to Table 6:

[1]Effectiveness rating and multiplication factor

4 = very high	1.00
3 = high	0.75
2 = moderate	0.50
1 = low	0.25
(-) = zero or N/A	0.00

[2]For the conditions under which the maximum fuel saving potential numbers were derived in Sections 3.1.

[3]Fuel saving for planning purposes taken as one-half of the potential saving as defined above, except when the device is particularly effective.

[4]Cost is estimated for a quality product under competitive market conditions, including Canadian production.

[5]Cost-effectiveness expressed in terms of benefit-cost ratio, assuming a 3-year payback period. Each 1% fuel economy gain corresponds to a $22 discounted saving over the payback period (see Appendix A). A ratio higher than 1.0 indicates a cost-effective device.

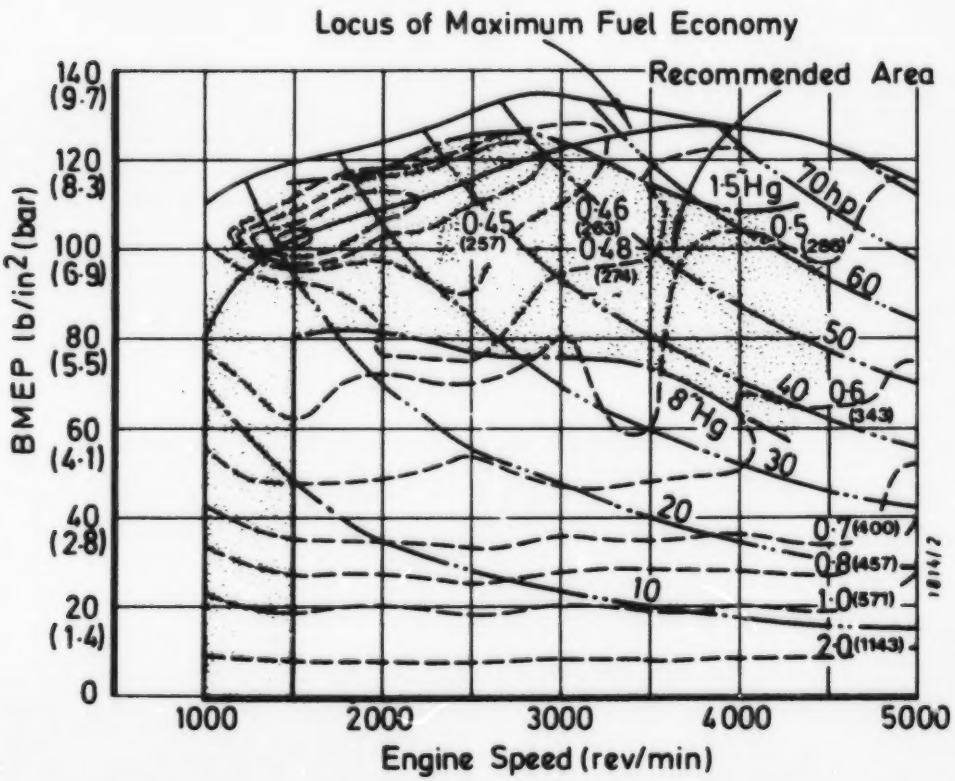

Figure 1/ Performance Map of an 1.8 L Engine Including Specific Fuel Consumption Contours

(Source: SAE Technical Paper 820167)

APPENDIX A/ BENEFIT-COST RATIO DERIVATION

Introduction

The basis for comparing the driver aid devices and recommending them for promotion or installation is the benefit-cost ratio. It establishes the monetary benefit of an item over its assumed lifetime of use by the original owner. All costs and returns are included -- the first cost (including installation), yearly operating cost increments (fuel cost saving, maintenance costs) and return from resale. A device is cost-effective to the consumer if the benefit-cost ratio exceeds one.

The series of costs and returns, all of which have been expressed in dollar terms, will be reduced to the present worth. This takes into account the time value of money -- specifically, that the utility of money decreases the farther one is from its receipt.

The present worth is determined by applying discounting techniques to the costs and returns distributed over the assumed lifetime of use. Discounting is the inverse of (interest) accumulation. If one knows the amount of a sum of money at a given time, one can determine its value at a later day by accumulating it forward to a compounded amount. Correspondingly, if one knows this compounded amount (a future cost or return in this case), its value at any prior time can be found by discounting it backwards to the present value.

Estimation for Current Study

A benefit-cost ratio calculation that includes all costs and returns would be appropriate in a comprehensive evaluation of driver aid devices. A simple benefit-cost ratio estimate that does not take into account the maintenance costs nor the resale return, which tend to cancel each other, is considered adequate for the preliminary comparison provided in this report. Thus the benefit-cost ratio becomes simply the summed discounted fuel cost savings divided by the first cost of the device. The lifetime of use is assumed to be three years, equal to the average duration of the first ownership of a car in the 1970s.

It is assumed that a device is installed on a typical 1980 car consuming 12 L/100 km and accumulating 16 000 km/yr. This gives a total fuel consumption of 1920 L/yr and corresponds to a cost of $864 and $0.45/L. Thus, a 1% fuel economy gain amounts to a yearly cost saving of $8.64. It is further assumed that any inflation is balanced by a proportional increase in fuel cost and that the yearly cost saving in current dollars remains constant.

An interest rate of 12% compounded semi-annually is used in discounting fuel cost saving. With that, using the average discounting periods of 6, 18 and 30 months for the 1st, 2nd and 3rd year, respectively, a 1% fuel economy improvement yields a total discounted fuel cost saving of $22 over the three-year lifetime.

POOR

QUALITY

ORIGINAL